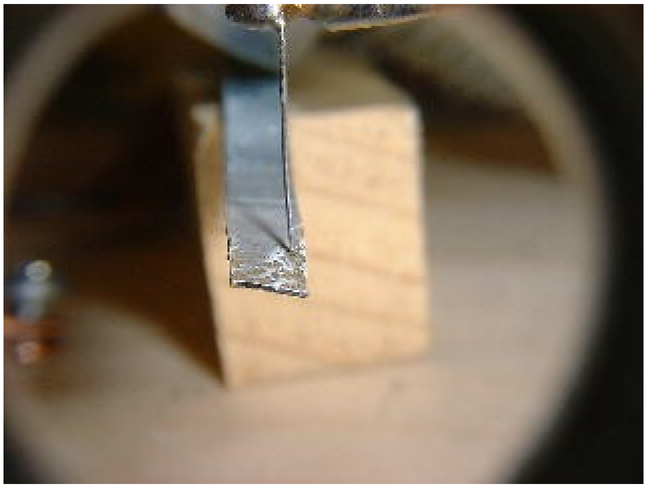
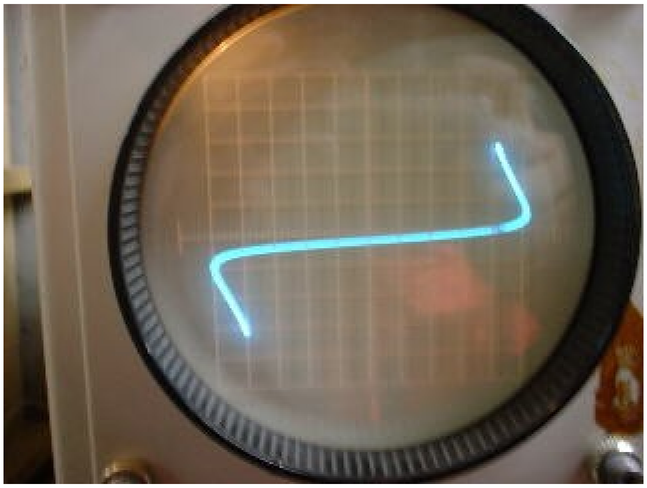
Zinc Negative Resistance Oscillator.

By Nyle Steiner K7NS 22 March. 2001

Anyone with a propane torch and a few scraps of galvanized sheet metal laying around can easily make a negative resistance device. With this device, it is possible to make very simple RF oscillators, audio oscillators and even amplifier circuits. It is almost like making your own transistor.

Heat treated galvanized metal strip and curve produced.





Negative Resistance from heat treated galvanized sheet metal. Curve tracer is set at 1v/div. horiz and 1ma/div. vert. Curve tracer was modified to apply ac to the device.

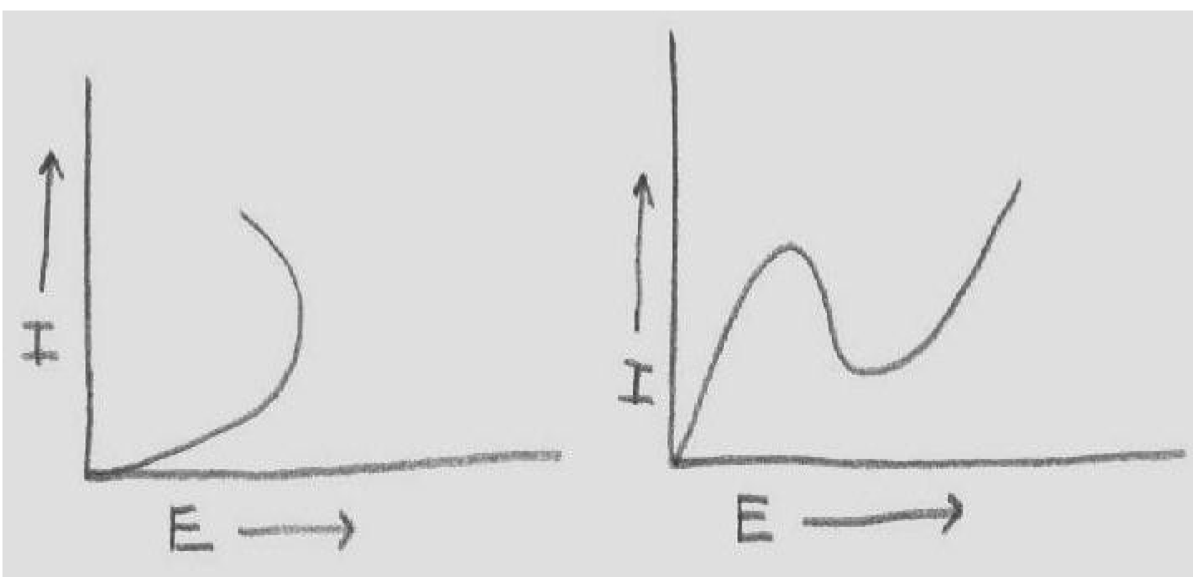
This project was sucessfully done earlier using iron pyrites (see Iron Pyrites Negative Resistance Oscillator) [Iron Pyrites Negative Resistance Oscillator] The heat treated galvanized device however, is much superior in ease of use, consistancy and is very easy to

prepare. As with the Iron Pyrites oscillator, success with this experiment has been a very exciting experience for me as it represents the ability to build a simple homemade active semiconductor device. It is almost like making your own homemade transistor. This is an actual realization of some very old, and esoteric 1920's experiments, by W.H. Eccles, Greenleaf Pickard and Oleg Losev, that were so vaguely reported in a few articles that I have often wondered if in fact it had actually been done. Even so, I have always had an extreme fascination with those reports of being able to produce a continuous wave RF signal from a crude semiconductor matarial back in the very early days of radio. From my experiences in experimenting with negative resistance materials, I can now say that those experiments done in the early days of radio, appear to be valid factual reports.

My fascination led me to purchase an old Tektronix 575 curve tracer so I could study the curves of various materials that might have negative resistance or detector properties as used in crystal sets. The curve tracer is not necessary in order to make and use the negative resistance device and circuits as described below. It is instrumental however, in the evaluation and discovery of materials which posess unique electrical properties. The 575 is a vintage but great tool because it continuously shows the curve in real time as you manually manipulate the samples. This is what is needed in order to make observations while manually touching a piece of wire to a piece of material. I wanted to be able to display both the positive and negative portions of the curves simultaneously and so had to modify the curve tracer in order to do so.

Some articles refer to this negative resistance as being like that displayed by a tunnel diode. It is true in the sense of having negative resistance, but it is in fact a different type of negative resistance. This is ok since both types of negative resistance can have the effect of gain, supplying enough energy to an LC circuit for it to become an oscillator.

Two types of negative resistance.



Left is type found in the galvanized sheet metal device. Right is type like a tunnel diode.

The figure above shows how the two types of negative resistance curves are possible. These drawings show the curves with the devices being biased in only one direction. The two forms of negative resistance are sometimes called type S and a type N. The S type is the type found here and in other devices such as a unijunction transistor and the old carbon arc oscillators. The upper portion of the S curve is sometimes not seen because some devices, such as the galvanized sheet metal device will destroy themselves before carrying enough current to display the upper portion of the S type curve. The type of negative resistance curve produced by a tunnel diode resembles the letter N. See also homemade N type device. **Homemade Tunnel Diode and RF Oscillator.**

Making the galvanized sheet metal negative resistance device is very easy. Simply hold, using pliers, the end of a thin 1/8 inch wide strip of galvanized sheet metal, of the type used for furnace ducts, in the flame of a propane torch until it glowes bright red and shoots out whit hot flares. It is a good idea to do this out of doors and to avoid breathing any of the smoke or fumes. People who are knowledgeable about welding say that poisonus fumes are produced when welding galvanized metal. After cooling, small dark spots will appear, especially on the side opposite where the flame has struck. These dark spots are the main negative resistance areas. The catwhiskers tried were 28 gauge steel wire and 30 gauge copper wire. Both seemed to work well.

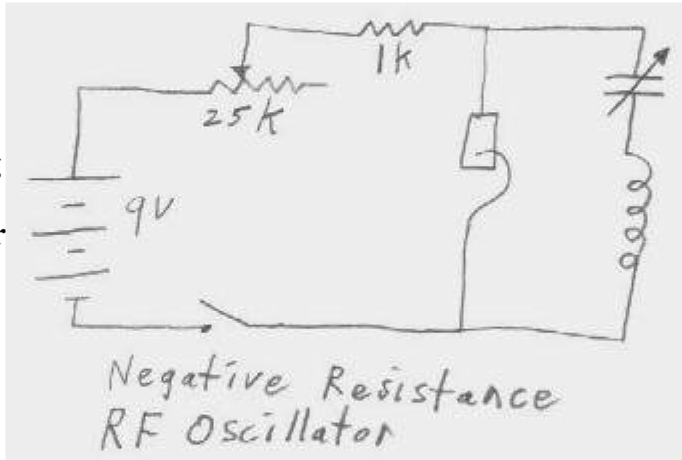
A good catwhisker arrangement can be made by putting two screws into a piece of wood about 1-1/2" square near the edge. A piece of #28 gauge steel wire can be wrapped around the two screws and cut to about 3" in length. The wire is then bent in an arch so that it lightly touches the heat treated metal as the block is moved around. A heavy weight on the block will make its position stable after making adjustments.

As can be seen on the curve tracer photo above, the curve can be quite symmetrical in both the negative and positive direction, although I sometimes would observe a somewhat asymmetrical curve. This picture was taken while the curve tracer was applying ac to the device. I had to modify the curve tracer so it could apply ac.

Oscillator circuits can be made that run easily from one 9v battery. It often seems easier to obtain steady oscillation when the catwhisker is biased negative with respect to the metal strip, but biasing in either direction can work.

Negative resistance RF oscillator using galvanized sheet metal.

The circuit shown is all that is necessary to produce a continuous wave signal in the am broadcast band. It seemed difficult to get it to operate above 2mhz but was easy to get it running at anything below that, including audio frequencies. It seems to prefer certain LC ratios better than others. In the case of the am



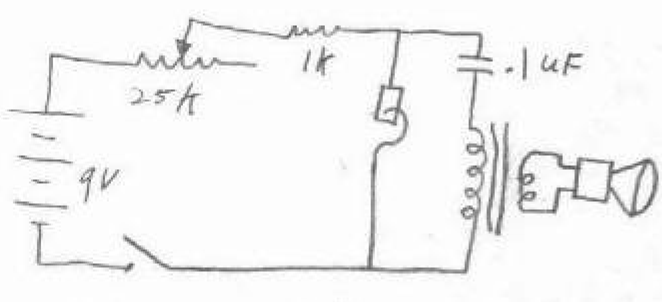
broadcast band, A 365pf variable capacitor worked well with 50 turns on a piece of 1 3/4" outside diameter abs pipe.

The trickiest part of getting this circuit to operate is to be able to tell when it is oscillating. The easiest way is to have an oscilloscope across the coil or across part of it with a tap. You simply make adjustments until you see the signal appear on the scope. It can also be done by adjusting the catwhisker while rocking the variable capacitor back and forth through its range and listening with an am receiver. This takes a bit more skill but it can be done. Another way to tell if it is oscillating is to put a diode and microameter across part of the coil. When a steady deflection of the meter is obtained, the variable capacitor can be tuned to the desired frequency using a receiver.

A good place to start making adjustments is with the pot set so that there is a total resistance of about 4k ohms including the 1k resistor. The only function of the 1k resistor is just to prevent a large amount of current flowing when the pot is set at zero resistance. Some settings of the catwhisker allow the circuit to oscillate over very wide variations of resistance (pot) settings.

Negative resistance audio oscillator using galvanized sheet metal.

The audio oscillator is much easier to adjust and to get running. It is simply a matter of listening for a tone from the speaker or headset while making catwhisker adjustments. As with the RF oscillator, a good place to start is with the pot set so that there is a total resistance of about 4 kohms including the 1k resistor. Some settings of the catwhisker will make the circuit able to operate over a very wide range of resistance settings. You may find it easy to get the circuit going with just one 4.7k resistor in place of the pot and 1k resistor.



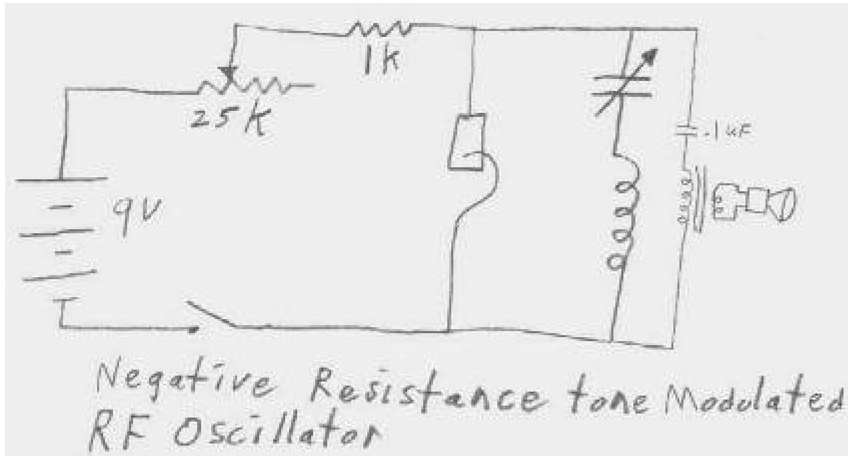
Negative Resistance Audio Oscillator

This audio oscillator circuit can use the 120 volt side of a 120 volt to 12 volt transformer or the 2k side of a 2k to 8 ohm transformer for the inductor. The output side of either of these transformers, 12 volt or 8 ohm respectively, can drive a speaker with enough volume to be heard across the room.

A pair of headphones of just about any impedance can be used in place of the speaker. A headset will present less of a load than a speaker and will result in a higher Q LC circuit. This can make it easier to obtain catwhisker settings that work well.

Negative resistance tone modulated RF oscillator using galvanized sheet metal.

A tone modulated rf oscillator can be made by connecting both an rf LC circuit and an audio frequency LC circuit across the negative resistance. This circuit can oscillate at both rf and audio frequencies at the same time. It is possible to adjust the circuit by listening to the speaker or earphone and then tuning the variable capacitor untill it is heard through an am radio. With many settings, a loud, well modulated tone will be produced.



It is interesting to note that it is possible to get combinations of pot and catwhisker settings where the audio circuit will oscillate but the rf circuit will not, the rf circuit will oscillate but the audio frequency circuit will not or where both circuits oscillate at the same time to produce the tone modulated rf signal.

Negative Resistance AM Broadcast band Oscillator.

It is possible to broadcast audio to a nearby am radio if a carbon microphone or audio transformer is placed in series with the battery supply. It is hard to beat the fun of broadcasting to a nearby radio with an electrified crystal set.

Negative Resistance Audio Oscillator.

Negative resistance audio oscillator driving speaker with enough volume to be heard across the room.

How did I find out about galvanized sheet metal anyway?

A while ago, I wanted to make a simple electric buzzer using a coil of wire wrapped around a bolt and a piece of galvanized sheet metal for the moving armature. It was of the DC type where a contact point touches the metal and electrical contact is broken whenever the magnet is energized and pulls the metal. This crude homemade buzzer worked as well as one might expect but, it would not run very long. Some kind of black oxidation crud kept building up where the metal was sparking against the electrical contact point and preventing good electrical contact. Being somewhat disappointed, I dismantled the buzzer and set the piece of armature metal aside where it sat around thereafter. Some time later, after experimenting with negative resistance in iron pyrites and similar materials, I decided to try the curve tracer on the black crud spots still on the galvanized sheet metal buzzer armature. The results looked promising. This lead to heating another piece of galvanized sheet metal in a propane flame. I was very pleased to discover many points that displayed very usable negative resistance. I had finally found a negative resistance material that could be consistently and confidently adjusted; usually within a matter of seconds.

After the metal is cooled, many black spots are found, surrounded with snow white powdery zinc oxide. The white zinc oxide acts like an insulator and shows no continuity whatsoever. The black spots are where most of the negative resistance is found. Taking a wild guess, I would suggest the possibility of these dark spots being Zinc Ferrite Zn-Fe2-O4 or something similar, formed by the interaction of heat, oxygen and zinc, reacting with the surface of the iron. The side of the metal facing away from the flame would be more more likely to be in contact with oxygen than the side facing the flame. That may be why I seem to find more good negative resistance spots on that side. Zinc ferrite is described in the Handbook of Chemistry and Physics as a black material. It would appear that zinc is playing an important role in the negative resistance. It stands to reason since zincite is mentioned in early radio articles, as one of the best negative resistance materials. It would be interesting to see what the curve, exhibited by zincite is like but I have yet to visit a rock & mineral shop that has a piece of zincite available. Perhaps the performance of the heat treated galvanized sheet metal is good enough to satisfy concerns about obtaining zincite.

Amplifiers using the negative resistance device.

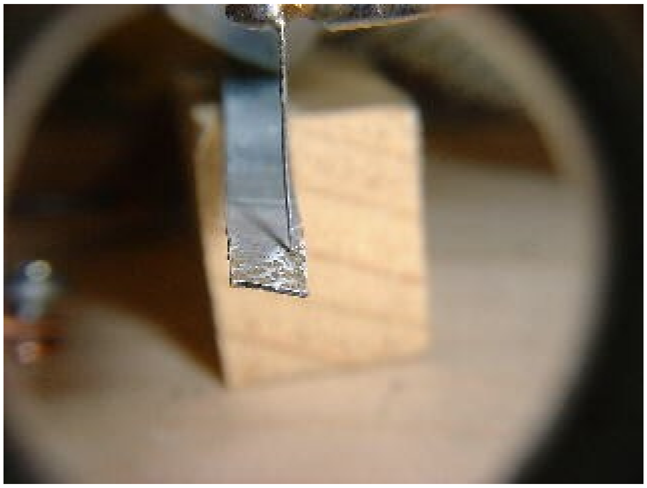
I have been somewhat successful in making some amplifier circuits from the zinc negative resistance devices. I have also been able to make a regenerative am broadcast band receiver. It seems much easier however, to make an oscillator than an amplifier with negative resistance because of the fact that most amplifier circuits have a great tendacy to oscillate unless adjusted very carefully. Before writing more about negative resistance amplifiers, I would like to put more effort into finding ways to get the most out of them.

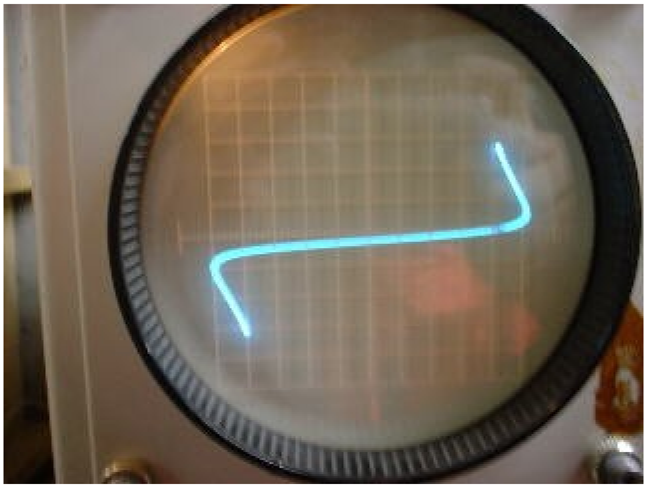
Spark, Bang, Buzz and Other Good Stuff. Home page.

Other Homemade Semiconductor Materials Make Negative Resistance Oscillator.

ByNyle Steiner K7NS 22 Mar. 2001

Heat treated galvanized metal strip and curve produced.





Horiz = voltage 1v/div. Vert = current 1ma/div.

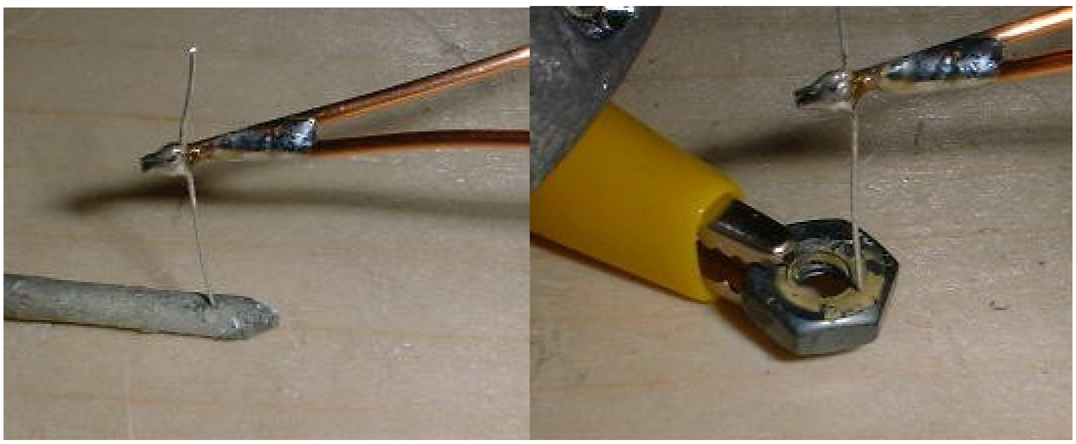
Refer to the previous article on the Iron Pyrites Negative Resistance Oscillator. Iron Pyrites Negative Resistance Oscillator I have found an easy way to make an excellent negative resistance material. This material appears to be superior to Iron Pyrites in ease of adjustment and consistancy in use.

The end of a thin 1/8 inch wide strip of galvanized sheet metal, of the type used for furnace ducts, was held in the flame of a propane torch untill it glowed bright red. It is a good idea to do this out of doors and to avoid breathing any of the smoke or fumes. People who are knowledgeable about welding say that poisonus fumes are produced when welding galvanized metal. After cooling, small dark spots would appear, especially on the side opposite where the flame struck. These dark spots are the main negative resistance areas. The catwhiskers tried were 28 gauge steel wire and 30 gauge copper wire. Both seemed to

work well. The circuit (as with the iron pyrites) seems to be very forgiving as to applied voltage level (pot setting).

As can be seen on the curve tracer, the curve can be quite symmetrical in both the negative and positive direction, although I sometimes would observe a more non symmetrical curve. It is also possible that applied dc could have some cumulative effect on the symmetry of the curve. This picture was taken while the curve tracer was applying ac to the device. I had to modify the curve tracer so it could apply ac.

The oscillator circuit can be run easily from one 9v battery and it seems easier to obtain steady oscillation when the catwhisker is biased negative with respect to the metal strip. Some steady oscillation was obtained however with the catwhisker positively biased. As with the Iron Pyrites oscillator, the frequency range seems to be limited to about 2 mhz.



Heat treated galvanized nail and zinc chromate nut. Either can produce oscillations. Nail was somewhat difficult to adjust but nut was easy.

It seems that anything associated with zinc can make a negative resistance device. Even the heat treated galvanized nail can produce oscillations with careful adjustment. A heat treated zinc chromate 6-32 nut seemed to work very well and was very easy to adjust.

I was able to obtain audio frequency oscillations using a piece of heat treated steel music wire but operation was unreliable and djustment was very difficult.

I was also able to get steady oscillations using some labatory grown pure bismuth crystals from a rock and mineral shop. It had a dark bluish color from a thin coating of bismuth oxide. It was a lot more stringent in it's voltage adjustment. The Bismuth oxide can have many interesting colors caused by light interference in the oxide coating.

I also obtained steady 40 mhz oscillations from a piece of pure silicon obtained at a rock and mineral show. It was supposed to be a byproduct from the semiconductor industry. It seemed to have a mind of it's own, oscillating between 10 and 40 mhz even though it was connected to an AM Broadcast Band LC circuit. It is also interesting stuff, but being from the sophisticated semiconductor industry, tends to defeat some of the fun of making an active semiconductor from materials found at home.

March 2002. A negative resistance device that seems almost indistinguishable from the heated galvanized sheet metal device was made by bringing a red hot flattened nail head in contact with a burning piece of magnesium ribbon. This seems to work about as well as the heated galvanized sheet metal for producing audio oscillations. Rf has not been tried yet.

I will try to keep this document updated for future developments.

Broadcast a Signal on a Magnetic Field.

A Magnetic field created with an audio AC voltage can be picked up and heard with a pickup coil plugged into a small amplifier. This magnetic field can be made to fill an entire house by running one turn of copper wire around the house and driving it with the speaker output of a small transistor radio.

Why does this magnetic field fill the entire house?

This experiment shows that the size of a magnetic field has nothing to do with its strength but with the size of the coil that produces it. Try the above experiment again but instead of driving the wire around the house, drive a loop that is only 3 inches in diameter and see how far you can get and still hear the signal. You will only get a few feet at best. Imagine having a loop of wire around the earth! The earths magnetic field is a large one; one that acts as though it were produced by a huge current carrying coil wrapped around the earth out in space. The earths magnetic field is not a strong one but an observer can travel many miles without noticing much difference in its intensity. A magnetic field produced by a small coil will diminish greatly when observed only a few feet away. If one could make a coil around the earth and drive it as in the above experiment, you could probably pick up the sound from anywhere on the planet.

The drawing shows why this is so. Notice that all of the lines inside of the coil are all running the same direction. These lines will all have a similar influence on a pickup coil that is placed anywhere in the coil. Notice however, that the lines of force at a considerable distance from the coil tend to be going in opposite directions and thus tend to cancel each other.

So now we can start to see why radio waves travel so far!

It is my belief that radio waves are nothing more than a simple magnetic field as described above, that is produced as though it came from part of an infinitely large coil. How can this be. Normally, we think of a complete circuit being required in order to carry current through a wire. It is this current that produces the magnetic field. In the case of AC however, current can flow through a wire back and forth if the wire is long enough. A complete circuit is just plain not necessary. At radio frequencies, the wire does not have to be very long in order to get current to flow back and forth without a complete circuit. A simple piece of wire stuck into the air will radiate a magnetic field and thus radiate a radio signal if it is driven with an ac signal that is high enough in frequency to make significant current flow through it. There is no "other side" of the coil to create any cancelling magnetic fields as you get far away from the antenna.

Rite about now you may be asking, "What about a Loop Antenna?" The answer is that the transmitting Loop Antenna is usually of significant size in comparison to the wavelength of the radio signal being radiated. This means that the magnetic fields from the loop cancel in some places and actually reinforce each other in other places.

That's it!! A piece of wire stuck up in the air makes a great antenna as long as an ac current can be driven through it. The only reason very low frequencies are not normally used for radio communication, is because of the prohibitively long lengths of wire required to make an antenna. If the wire is not long enough, the current arrives at the end long before it is time to reverse and flow in the opposite direction. At high frequencies, the current keeps reversing before the electrons can travel very far in the wire and thus AC current flow is possible in a reasonably short wire.

Misconception No. One!!

1. Radio frequencies are always higher than those of sound.

When we are taught about the spectrum of frequencies, we tend to get the misconception that radio frequencies are always higher than audio frequencies and that the main difference between an audio signal and a radio signal is their frequencies. Nothing can be farther from the truth. The main difference between an audio signal and a radio signal is that an audio signal is vibrating air and a radio signal is a vibrating magnetic field. Radio frequencies are part of the electromagnetic spectrum and sound is part of the acoustic spectrum. Even though Sound and Radio signals involve two separate mediums or spectra, their frequency ranges can certainly overlap. Audio signals in the air can be produced at frequencies well into the multi tens of kilocycles, while radio signals can be produced at frequencies way down into the audio spectrum or lower. As stated above, radio signals in the audio frequency range are less common because of the very long antennas needed to radiate them.

Misconception no. Two!!

Standing Wave Ratio is a sacred antenna parameter!!!

If you study a lot of antenna literature, particularly that written for Ham Radio operators, you will get the impression that proper Standing Wave Ratio is the sacred key to good antenna performance. Actually, Standing Wave meters are mostly the result of modern radio transmitters being designed to drive only 50 ohm output loads. The easiest way to get a finger on matching an antenna system to this 50 ohm transmitter is to use a meter that tells if the load is matched to 50 ohms. Someone decided to get everyone involved in looking at the concept of "Standing Wave Ratio" instead of that of "Impedance Matching". In a way, the SWR meter gives an indication of both. It would have been a lot easier if they had put the emphasis on the concept of "Impedance matching" instead of "Standing Wave Ratio". The impedance matching concept is much more intuitive and is more of the real issue than the concept of standing wave ratios. The standing wave concept, being less intuitive, does not get to the real issue at hand. Many "Experts" talk above everyone and sound smart because no one can understand them. Of course they are hard to understand because they are not always making complete sense.

Impedance matching, by the way, is basically a concept of how some antennas can act like a 12 volt 50 watt light bulb or a 110 volt 50 watt light bulb. A power source for the 12 volt bulb will need to supply more current at less voltage and the power supply for the 110 volt bulb will need to supply more voltage at less current. Since different antennas can have different impedances, the transmitter must be able to supply power at different impedances.

This misconception about standing wave ratio is not just my own opinion. A good book on the subject is written by Walter Maxwell W2DU, an antenna specialist in the space program. His

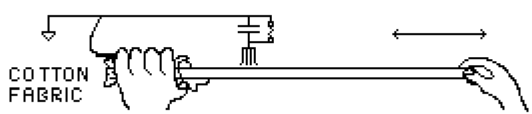
book is called "Reflections" and is published by the American Radio Relay League. It goes into great detail about the misconceptions surrounding "Standing Wave Ratio".

One of the best sources of Ham Radio literature on antennas is the Fifteenth edition of the ARRL Antenna Book copyright 1988. This edition finally makes a lot more sense when it comes to antennas.

Static Electricity Generator with PVC Pipe.

The choices of static electricity generator designs that are available seem to be either that of the simple Electrophorus or something much more complicated, such as the Wimshurst machine or the Van de Graaff generator which involve mechanical rotators, motors, belts, pulleys etc. This generator is extremely simple to make, but fills in much of the huge performance gap that exists between the Electrophorus and the Wimshurst machines etc.

The generator is made by using a piece of 3/4 inch pvc pipe about four feet long and a piece of cotton fabric. Paper seems to work quite well also. To operate, one simply holds the fabric or paper with the left hand wrapped around the pipe. The pipe is then pushed and pulled through the fabric, with large strokes, while holding the pipe near some fine wire tip pickups to collect the charge. The wire tip pickups can be connected to a leyden jar or electrostatic motor etc. It is also a good idea to hold in the left hand, along with the fabric, a piece of metal that is connected to ground. This gives the generator a good voltage reference point and keeps the body from building up a big charge that will zap you the next time you touch a grounded object.



Electrostatic Generator

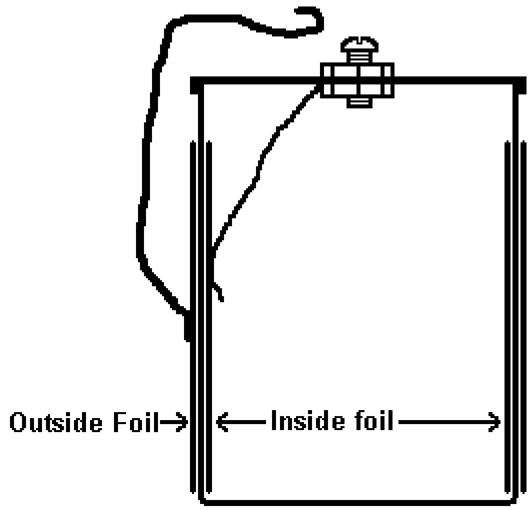
With the spark gap set at about 1/4 inch, a spark can be produced across it with almost every stroke of the pipe. This PVC pipe generator does a very good job of running an electrostatic motor like the one described here. This generator worked well for me even on a very wet rainy day.

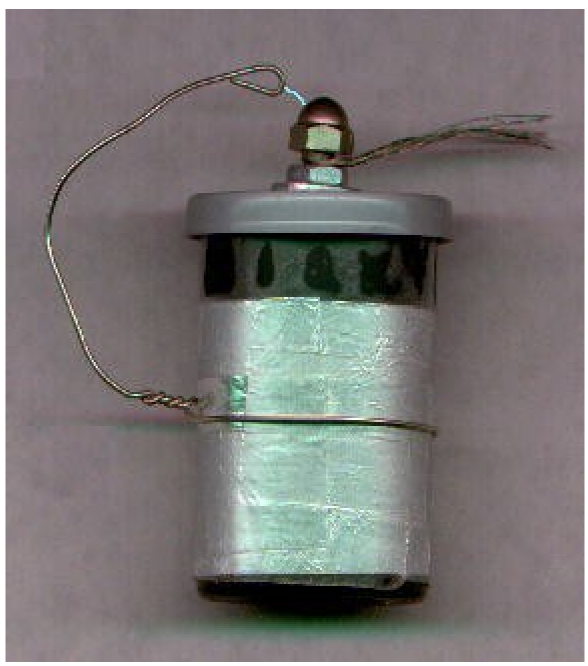
Static Generator.

Film Can Capacitor (Leyden Jar).

The electrostatic generator needs a place to store and build up an electric charge. Without the capacitor, a static generator such as the one made with PVC pipe would have to be operated in a very dark room in order to see any sparks produced. The capacitor stores up enough of a charge to make a very visible spark in broad daylight and, can also be heard.

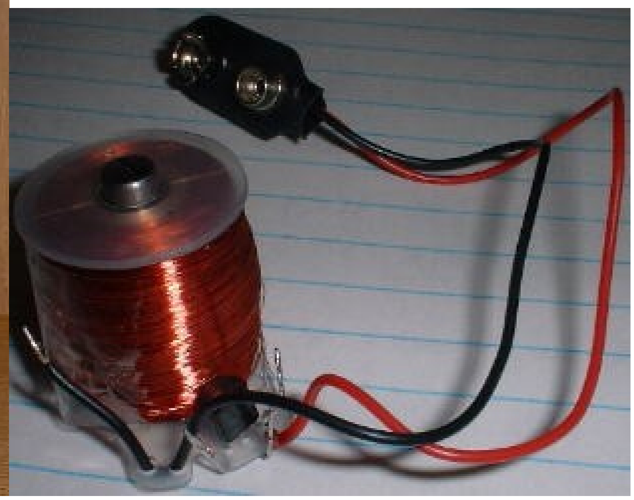
Film Can Capacitor (Leyden Jar)

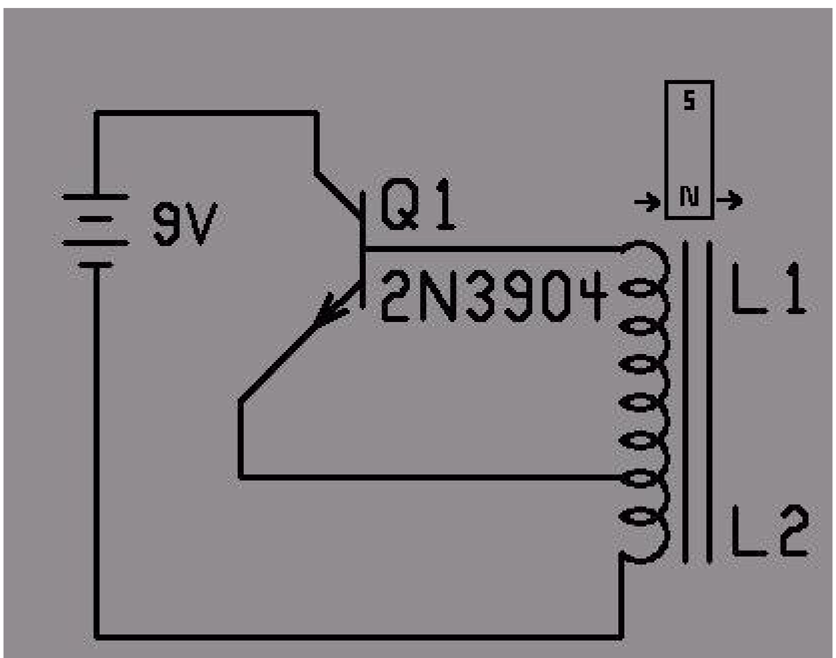




The picture of the film can leyden jar is self explanatory. Now days, a film "can" is really plastic but it is a kind of plastic that makes a great capacitor. The inside foil can be taped to the wall or secured any way you want, so long as it makes good contact with the wall. One person wrote back and reported that the film can exploded as a result of using rubber cement to glue the inside foil to the wall. Rubber cement is highly flammable and explosive and was set off by sparking inside.

Magnet Motor - Kicker.





Magnet Kicker Circuit.

Have you ever wondered how those magnetic motion toys work. The picture above shows one and what is inside it. The circuit is very simple. It consists of a coil around an iron core, an NPN transistor and a 9volt battery. That is it! No resistors, no capacitors; just the coil, transistor and battery.

The coil is in two parts. An inner coil to drive the moving magnet and an outer pickup coil with many many turns to sense the moving magnet and generate enough voltage to momentarily turn on the transistor. The two coils are wound as though they are one with a tap near one end. In other words, a single coil with a tap near one end would be phased properly when connected as shown in the diagram.

With no moving magnet near the coil, the transistor is biased completely off (small resistance of coil from base to minus) and no battery current is drawn. When a magnet moves near the coil, it generates a voltage pulse that turns on the transistor and pulls battery current through the low end of the coil. This energizes the core, enhances the drive pulse to the transistor base, and produces a momentary magnetic kick to enhance the movement of the magnet. The circuit only draws current from the battery during this short kick pulse.

The driver coil that is driven by the transistor can be seen as a lighter color near the core. It is wound of a larger diameter wire in order to carry a larger current supplied by the transistor. The outer pickup part of the coil is of very fine wire for many turns. The more turns, the more sensitive the circuit will be to a moving magnet. I estimated about 2500 turns on the inner coil and 8,000 to 10,000 turns on the pickup coil. The driver coil wire measured to be about 5.5 mil thick and the pickup coil wire measured to be about 3.5 mil thick. These measurements included the insulation enamel on the wire.

The polarity of the approaching magnet determines whether this kick happens while the magnet is approaching or while the magnet is leaving the core.

I was able to make my own magnet kicker motor by winding a tapped coil on an iron bolt. For simplicity, I used just one small wire size and wound it as shown (picture to come, check back later). I used some 3.5 mil wire that was handy. The transistor was an NPN 2N3904, but just about any bipolar transistor will work. I have also seen this circuit made with a PNP transistor.

I made an armature by simply gluing two disk magnets on to a piece of thin music wire with hot glue. I could make it run like a motor by loosely holding it and giving it a spin near the coil. The two magnets were glued on to the music wire in such a way as to similate a shaft passing through the middle of a bar magnet. The poles face 90 degrees from the music wire shaft so that one side of the armature is North and the other side is South.

Permenant Magnet Levitation.

A permenant magnet being levitated. No superconductors, no electrically powered feedback stabilization or spinning tops. It just sits there floating day after day by the interaction of two permenant magnets.

In spite of what Earnshaw said, I have always believed in the possibility of permenant magnet levitation. I found out about this at a very excellent web site called Scitoys.com. I highly recommend looking at it. I just had to try building one of these myself. It worked just like they said. The small magnet can be made to wobble around or spin by blowing on it. It is stable and always returns to its center position.

It is always annoying to me when someone flashes a bunch of mathematical mumbojumbo in our faces and says something is impossible. Many times the impossibility may be true in the true sense of the mathematical definition, but mathematical definitions often fall way short when evaluating our real and practical world. Someone named Earnshaw, using mathematical mumbojumbo, said that a permenant magnet can not be levitated without using some energy input for stabilization. In the practical sense, one would be a fool to take the Earnshawtherom seriously. The picture shows that permenant magnet levitation can easily be done at home.

The trick is a property of bismuth called diamagnetism. Diamagnetism is a property of a substance to be repelled instead of attracted by a magnet. It also has the peculiar property of not trying to rotate the magnet away from it during the repulsion. A diamagnetic material will be repelled from a magnet no matter what pole it is near. Diamagnetism probably does not fall within the definition of the Earnshawtherom but who cares.

The small floating magnet is repelled away from either of the bismuth plates and tends to stay in the center. The weight of the floating magnet though is many times greater than the diamagnetic force and would normally just sit on the bottom plate. The pull from the large magnet above however, is carefully adjusted to just counteract the floating magnet's weight.

I was able to achieve stable levitation with just one bismuth plate either above or below but the adjustment was more sensitive and the floating magnet, if jostled, could go unstable and either fall or be sucked up.

Bismuth seems to be one of the few materials that has enough diamagnetism to make this work easily. It can be obtained by taking bismuth shot from shotgun shells. They are a special kind that use bismuth shot instead of lead shot, to prevent lead poisoning to birds in hunting areas. Most of the bigger sports dealers carry the bismuth shells. I used two shells worth for each of the two bismuth plates shown. The shot was melted on my kitchen stove and poured into the bottom of an upside down pop can (it was handy as suggested by scitoys.com and is the only reason for their curved side).

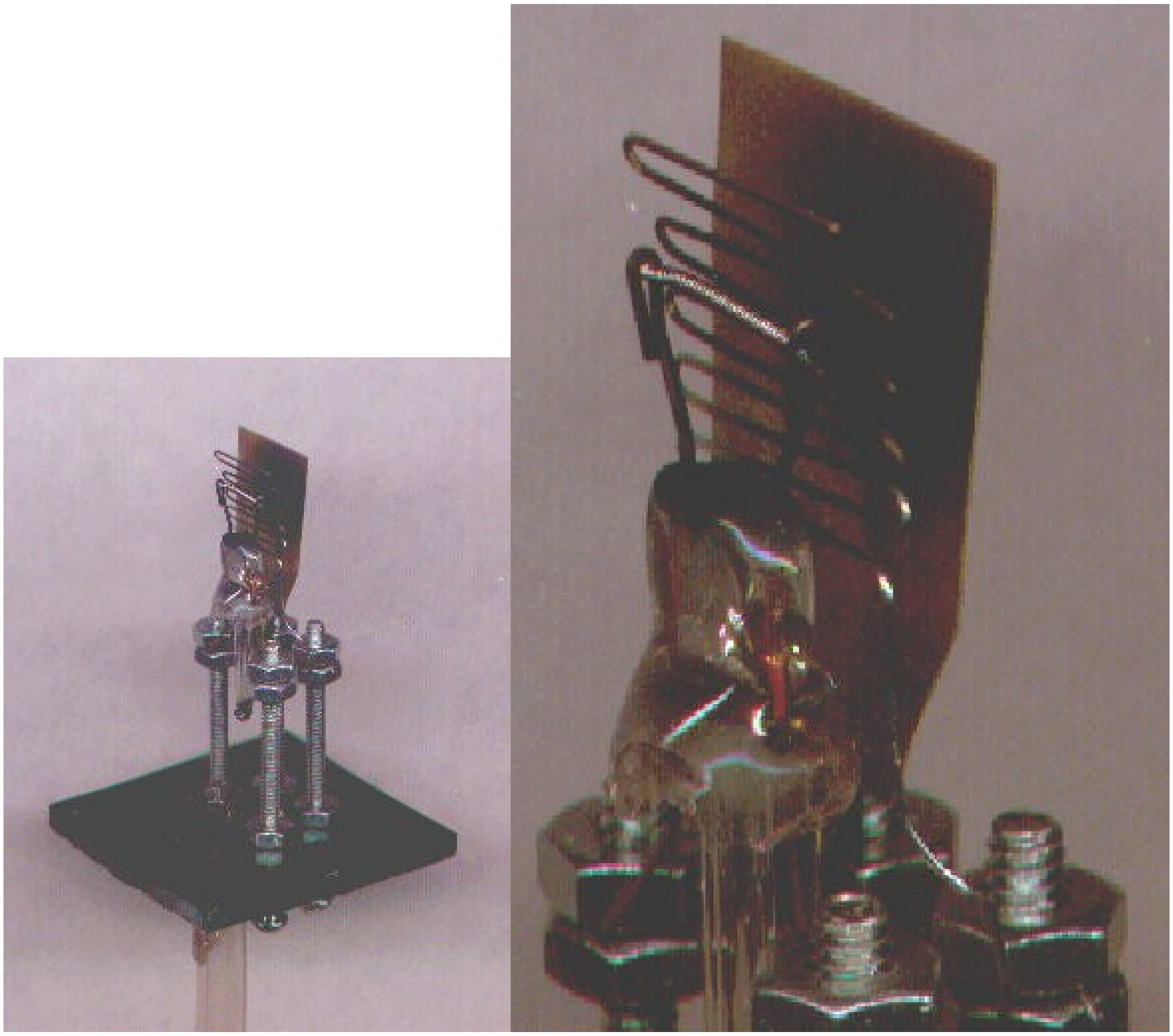
For obvious reasons, be sure to remove the bismuth shot from the shells before trying to melt it. I did it by prying the end (the end opposite the brass) of the shells open. The best way however, seems to be by cutting the end open with a razor knife.

The picture is pretty self explanatory. It is important to use a Neodimium Iron Boron magnet as the floating magnet because it is powerful enough to produce an adequate amount of diamagnetic force. I got mine at Radio Shack. The two pieces of bismuth are separated by two pieces of plastic that were handy. This separation distance is best determined by experiment. I have two NIB magnets from Radio Shack and one floats straight as pictured while the other one tends to float in a somewhat slanted position. Perhaps the slanted magnet was manufactured crooked.

The other important thing is to use a big strong magnet as the lifting magnet above. It must have a large magnetic field, compared to the small space where the small magnet floats. This makes a small magnetic strength gradient in the space where the magnet floats. This gradient must be smaller than the force gradient from the diamagnetic repulsion in order to keep it from being suddenly sucked up as it rises. An example of a large magnetic field is the earths magnetic field. We notice very little change in its strength as we travel miles. An example of a small magnetic field is one from a magnet held in the hand. We notice a drastic change in field strength by moving just one inch. As can be seen in the picture, the large magnet above is simply two large ceramic disk magnets stuck together on a piece of plastic. It is also important to support the magnet and plastic on nuts so that the height can be carefully adjusted. There is a very specific height that must be found by experimentation and turning the nuts.

This levitating process is similar to that of placing a magnet above a superconductor. The only difference is that the superconductor has a very much larger diamagnetic force that is sufficient to support the weight of the floating magnet. The magnetic field pulling from above is not necessary.

Homemade Vacuum Tube Triode.



15 June 2000.

This is my first attempt at making a completely from scratch homemade vacuum tube triode. There is not much more to say about the construction than what the picture says. The filament is from a car turn signal lamp, the grid is a piece of steel wire bent as shown and the plate is a piece of thin brass that was handy. They are all mounted with the screws shown. The screws are connected through a flat piece of ABS plastic and sealed on the outside with hot glue. A rubber gasket is laid on the plate around the outside and a small bell jar (actually a glass salt shaker) is set over the whole assembly before evacuating.

The triode was first tested on an old Tektronix 575 curve tracer. As with the homemade diode mentioned previously, it was necessary to apply almost the full 12 volts to the filament in order to get any action. Commercial vacuum tubes use some kind of thorium treated filaments which allow them to emit electrons at a much lower temperature. This filament, being just plain tungsten, had to be near its normal incandescent temperature in order to emit electrons. With the filament connected to a 12 volt battery, Tungsten seems to emit electrons very well; you just have to run it at a higher temperature. The higher

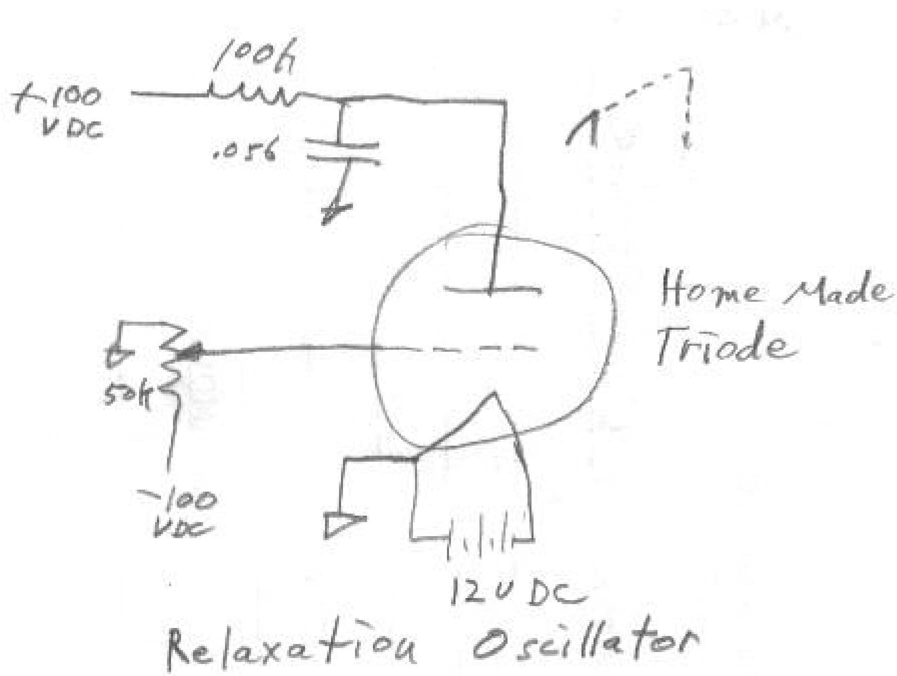
temperature, however, does seem to create an additional situation as I will try to theorize and explain below.

This homemade triode seems to be able to operate in two different modes. It can conduct current from the filament to the plate through hot filament electron emission or, through ionization of the residual air. When conducting through filament emission, it tends to behave like a normal amplifying triode where the plate current is controlled by a voltage applied to the grid. When conducting through ionized air, it acts more like a thyratron where the grid only controls the ionization breakdown voltage. Because the tungsten filament is running much hotter (near or at full incandescence), than a normal vacuum triode thoriated filament, the heat or brightness (Iam not sure which), brings the residual air close to ionization. This gives the tube a greater tendacy to behave like a thyratron.

It seems capable of behaving like a normal amplifying triode only at a plate current of about 20 microamps and less when the filament is run at a lower temperature. The plate current can be controlled with varying amounts of negative grid voltage. This tube did not seem to respond as much to positive grid voltages as did the home evacuated factory made vacuum tube. The point between where the filament is just hot enough to cause electron emission and the point where it is so hot as to cause air ionization defines a small window where the tube can operate at as a normal amplifying triode. Future attempts will be to make this window of operation bigger. I believe that the homepumped factory made triode worked better in this mode because its thoriated filament was emitting electrons at a lower temperature where the air was not so easy to ionize. I want to try to optimise this window of operation with the homemade vacuum triode.

The thyratron action worked very well and could carry much more plate current - in the many milliamp range. Ionization (breakdown) voltages between the filament and the plate could be adjusted all the way from about 25 up to the 100 applied plate volts by varying the grid voltage from zero to minus 35 volts. The Ionizing voltage was greatest with the grid at negative 35 volts.

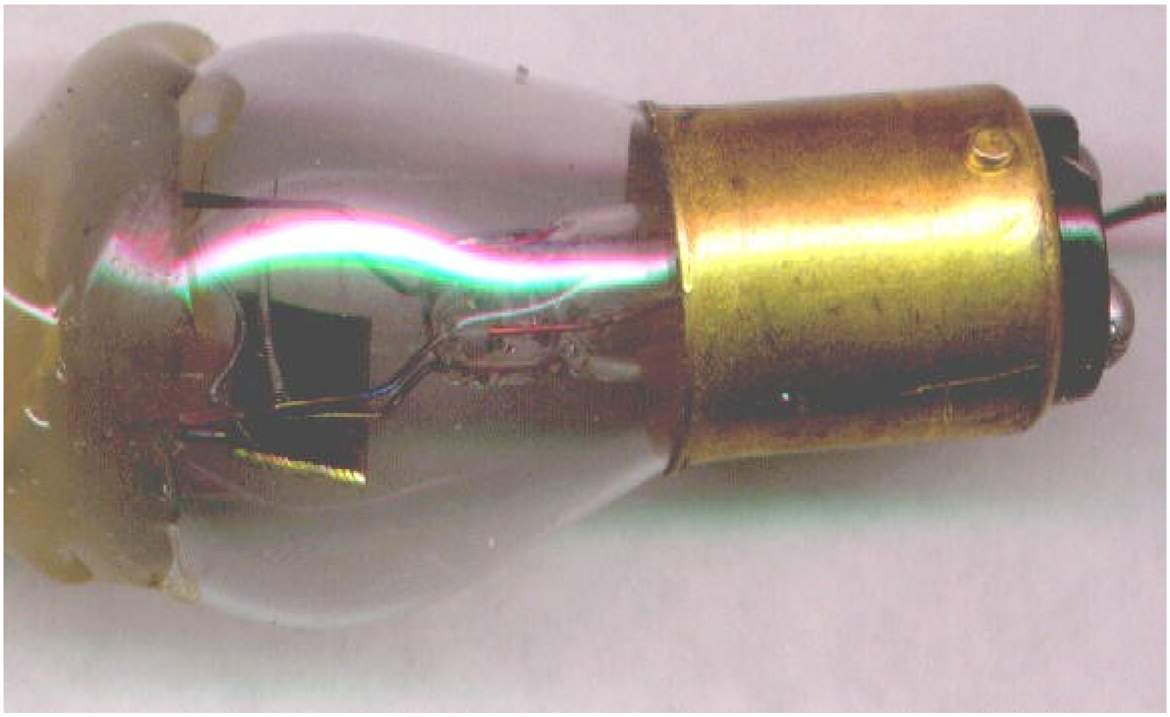
It was very easy to make a simple relaxation oscillator with this homemade triode operating as a thyratron. By varying the negative voltage on the grid, I could adjust the amplitude of the sawtooth waveform over a wide range.



I will point out that with up to 200 volts applied to the plate, no reverse current was observed during all of the experimentation. This was easy to check since I have modified the Tektronix 575 curve tracer to be able to apply ac voltages across its devices udner test. This means that it is easy to make a vacuum diode rectifier no matter what mode is used.

The tube was evacuated in the same way as the previous experiments using the two shageRobinair vacuum pump. Most of the experimenting was done at a vacuum of about 10 microns or below. The thyratron action seemed to work well however, up to 50 microns. I didn't operate the tube at much higher pressures in order to prolong the life of the filament.

Homemade Vacuum Tube Diode.



11 June 2000.

This is a follow up experiment from the report that I wrote previously about home evacuation of a vacuum tube. The next step is to make my own vacuum tube from scratch. This is my first attempt, a diode. The diode seems to work surprisingly well and makes the thought of putting a grid between the filament and the plate very encouraging.

The diode was tested on an old tektronix 575 curve tracer. It was necessary to apply almost the full 12 volts to the filament in order to get any action. Commercial vacuum tubes use some kind of thorium treated filaments which allow them to emit electrons at a much lower temperature. This filament, being just plain tungsten, had to be near its normal incandescent temperature in order to emit electrons. With the filament connected to a 12 volt battery, It was very easy to get well over 100 milliamps of plate current - very surprising! I have always wondered if it would be necessary to have a thoriated filament in order to make a vacuum tube. It definitely seems not. Tungsten seems to work very well; you just have to run it at a higher temperature.

The plate, with no voltage applied and connected to a dc voltmeter, produced negative two and one half volts. The curve of the plate conduction shows a slight amount of current increase up to several volts applied between the filament and the plate. After several volts,

the current starts to increase at a very steep rate with rise in plate voltage. I also noticed what appears to be a small negative resistance region in the curve at about 125 milliamps and 30 volts. This resembles the negative resistance region of a tunnel diode. I noticed similar things during the previous experiments with the vacuum tube. I can't be sure yet if the curve tracer is playing tricks of if there is something really interesting going on here.

The vacuum tube diode was made from an automobile tail lamp. As can be seen in the picture, the top was filed open with an abrasive stone made for filing glass. The hole in the top was made large enough to slip in a small brass plate and the evacuation tube.

The plate was a small piece of brass (.025 thick) soldered to a wire. The hose and the plate wire were hot glued to the top in order to make the seal and hold the plate near one of the filaments. The plate was spaced several millimeters from the heavy filament.

The tube was evacuated with the same Robinair vacuum pump as mentioned before. Most of the experimenting was done at a vacuum of about 10 microns or below, but it was easy to observe diode plate current with a vacuum of 50 microns.

Zinc Negative Resistance RF Amplifier for Crystal Sets and Regenerative Receivers Uses No Tubes or Transistors.

ByNyle Steiner K7NS 20 November. 2002

Negative Resistance R.F. Amplifier for Crystal Set.

Am broadcast band R.F. amplifier using a homemade negative resistance device.

I have found that building negative resistance audio amplifiers, especially for crystal sets, can be a challenge owing to the fact that their gain is greatly affected by their input and output impedances and also because of their tendacy to act as oscillators. I find that building a broadband audio amplifier is easy only if the amplifier is driving a pure resistive load. Inductive loads such as a transformer or headset, which are usually the easiest way to make use of this gain, present varying impedances over the audio spectrum. I have had

some success building negative resistance audio amplifiers that only produce gain into a headset over a narrow audio bandwidth. In addition, negative resistance amplifiers do not seem well suited for amplifying the audio output from a crystal set because of the low impedance that is usually required to drive the amplifier.

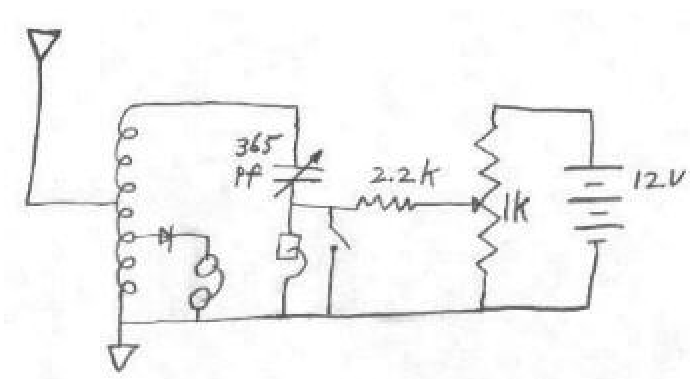
Using a negative resistance amplifier to amplify an RF signal however, is a much more straightforward task as only one frequency need be amplified and the impedances on the input and output can be easily chosen by using tap points on tuning circuits. An effective AM broadcast band RF signal amplifier can easily be made using the same homemade negative resistance device as is used to build the negative resistance oscillators written about earlier. This RF amplifier, is made with a simple homemade semiconductor device and uses no tubes or transistors. It can be connected to crystal set circuits to amplify the signal from the antenna or to make them into regenerative receivers. The main reason for building the receiver circuits described here is for the fun and satisfaction of doing it with a simple home made amplification device. To find out more details, about this homemade zinc negative resistance device, see:[Zinc Negative Resistance Oscillator]

Two circuit configurations are shown below. The coil is wound on 1 1/2 abs pipe with taps every ten turns. The variable capacitor and detector diode tap points should be chosen for best band coverage and optimal headset volume.

These amplified circuits seem to work best with lower strength radio signals. In my location, there are a couple of very close radio stations that just tend to overwhelm the circuit. In order to simulate weaker signals, I have been using a 12 to 15 foot antenna wire strung up across the ceiling of my basement room. With the RF amplifier connected, I can hear stations through the small indor antenna at a level similar to that of using a much larger and higher outdoor antenna. It is sometimes possible, especially with the regenerative configuration, to hear the audio hetrodyne with the incoming signals.

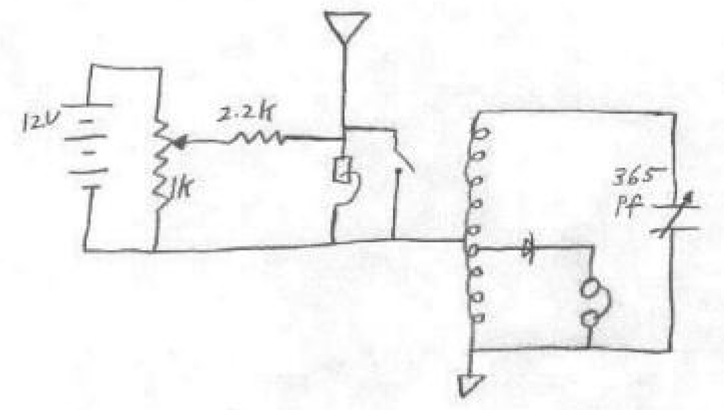
I also tried using this amplifier on a friends crystal set located where there are no strong signals. I was able to clearly hear and understand a station that was otherwise too weak to be intelligable.

Regenerative Receiver.



RF amplifier made from homemade zinc negative resistance device is connected to crystal set in a regenerative receiver configuration.

Crystal Set with RF Amplifier.



RF amplifier made from homemade zinc negative resistance device, is connected in series with crystal set antenna.

Making the galvanized sheet metal negative resistance device is very easy. Simply hold, using pliers, the end of a thin 1/4 inch wide strip of galvanized sheet metal, of the type used for furnace ducts, in the flame of a propane torch until it glowes bright red and shoots out whit hot flares. It is a good idea to do this out of doors and to avoid breathing any of the smoke or fumes. People who are knowledgeable about welding say that poisonus fumes are produced when welding galvanized metal. After cooling, small dark spots will appear, especially on the side opposite where the flame has struck. These dark spots are the main negative resistance areas.

A good catwhisker arrangement can be made by putting two screws into a piece of wood about 1-1/2" square near the edge. A piece of #28 gauge steel wire can be wrapped around the two screws and cut to about 3" in length. The wire is then bent in an arch so that it lightly touches the heat treated metal as the block is moved around. A heavy weight on the block will make its position stable after making adjustments.

For this amplifier to be effective, the optimum point, where the antenna taps into the coil, should be found. Negative resistance amplifiers are very fussy about the impedances they are connected to. One part of the band seems to require a different tap point than another part of the band. Each time a different station is tuned, different antenna tap points should be tried. I have had good success adjusting the circuit as follows. Close the switch across the zinc device. This disables the amplification and makes the circuit as a normal crystal set. Choose a point on the coil and tap the antenna into it there. Adjust the variable capacitor until you hear the station that you want. Open the switch, enabling the gain, and move the catwhisker around while at the same time varying the bias pot. When you find a catwhisker spot that makes a sudden jump in volume or hetrodyne type of sound, leave it there and make adjustments to the pot and variable capacitor for optimum volume. If you don't have much success, try connecting the antenna to a different tap point on the coil and make the above adjustments again. Certain settings of the pot will sometimes cause distortion. The idea is to adjust the pot for the highest volume without a lot of signal distortion. With some practice you should be able to get impressively higher volume levels than what can be obtained when the gain is disabled.

The configuration that amplifies the antenna signal was shown in a very excellent two part article from The Wireless World and Radio Review October 1, 1924 and October 8, 1924 entitled "The Crystal As A Generator And Amplifier" by Victor Gabel. The article also includes several regenerative receiver circuits that utilize the negative resistance device for both RF amplification and detection. I have had success in the past building similar regenerative receiver circuits but greater headset volume is produced when using an additional detector diode, as I have described here. This article was found by Ken Ladd and is absolutely the best article I have seen on the very esoteric subject of oscillating crystal experiments performed in the 1920's. What a find this was!!! This article is very generous with explanation, details and schematics. There is at present a question regarding the ability to mass distribute copies of this article because of copyright but it is being looked into.

I must point out that the term "oscillating crystals", as used here, should not be confused with the piezo electric resonant crystals used nowdays to control oscillator frequencies. The early negative resistance experiments were performed using the same crystal substances as were used to make detectors.

Most of the experiments in many of the old 1920's article talk about the use of zincite as the most successful negative resistance material. Some articles state that the zincite must be that which is obtained from one place in the world, Franklin N.J. It is my opinion after experimenting, that the simple home prepared heat treated galvanized sheet metal can be used in most if not all cases, as a substitute for the zincite.

When reading various articles about the performance of crystal sets, one must be careful about taking a lot of performance claims to seriously, owing to the many many undocumented variables. Many will report about how something works as a detector for example, but no information or definition is given to how powerful of station is being listened to or how far away it is. One person might write about how a certain material works well as a crystal set detector but for all we know, they may be one block from a 50 kw radio station. Another report may be written by a person who was 20 miles from the nearest station. Under the circumstances of being one block from a 50 kw station, almost anything would work as a detector; you would hear something, almost no matter what kind of circuit or antenna is tried. I once knew a person who lived next to a 50 kw am broadcast station. He was always hearing the station while using his normal telephone. Many of the reports given by individuals about how well a crystal set works for them, are short on documentation about their location and circumstances concerning the strength of the signal being received.

There are also numerous claims in vintage literature, of being able to get amplification in a crystal set by connecting a battery to the circuit or detector in some way or another. It is probable that many of these increases in volume are not from amplification, but merely the result of making the detector more efficient with biasing. Many types of detectors require a small bias voltage across them in order for them to work well. Getting a louder signal when a battery is connected has probably made many think that the circuit is amplifying when in reality, it may have just been loosing less of the signal than it was before.

I wish to clarify these points and assure the reader of this article, that all observations of gain in the circuits described herin, have been made with the above points in mind.

Another configuration for using the negative resistance device is to use it as a simple CW RF oscillator or tone modulated RF oscillator. See circuit below. Through a nearby crystal

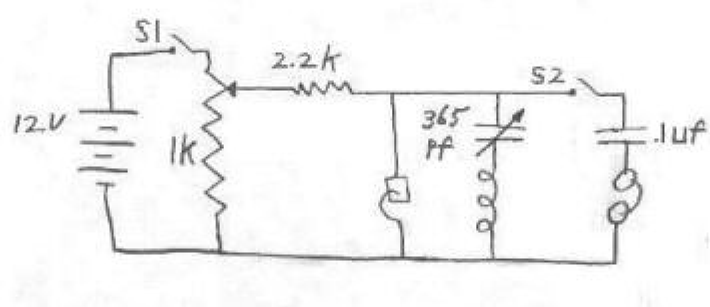
set it is possible to hear this oscillator as a hetrodyne with incoming signals or as an audio tone. Why would anyone want to hear a hetrodyne with an incoming broadcast station? Mainly for the rush it gives when you realize you have just made a tiny transmitter using a homemade semiconductor.

Closing S2 puts the circuit in the tone modulated RF mode by including the phones and the .1uf capacitor. This forms an audio frequency LC circuit. In this configuration, the circuit can oscillate at both an RF and an audio frequency at the same time. The tone can be easily heard on a properly tuned nearby crystal set.

The tone modulated mode makes adjustment of the catwhisker easy when listening for an audio tone in the phones. This tone modulated circuit makes a very effective code practice oscillator if S1 is replaced with a key. You can hear the tone through the phones in the circuit or through a nearby radio. An element of excitement would be added to the teaching of morse code to students when they realize they are actually hearing the signal from a tiny nearby transmitter. Take out the RF LC part of the circuit, and you still have an audio code practice oscillator by listening through the phones.

When making adjustments, it is necessary to listen for both an audio tone in the phones and in the nearby crystal set. This is because some settings can cause just the audio portion of the circuit to oscillate. Other settings may cause just the RF portion to oscillate. Hearing the tone in the phones and the nearby crystal set indicates that both audio and RF circuits are oscillating. When this condition is achieved, open S1 and then S2. When you close S1 again and you will usually have a CW RF oscillator which can be heard on the nearby crystal set. Of course the variable capacitor must be tuned to adjust the oscillator frequency to the crystal set frequency. The oscillator coil may need to be set near enough to the crystal set that it interacts with the crystal set coil. Opening S2 without opening S1 first, has a tendacy to destroy the negative resistance setting.

Hetrodyne Oscillator or Tone Modulated Transmitter for Crystal Set.



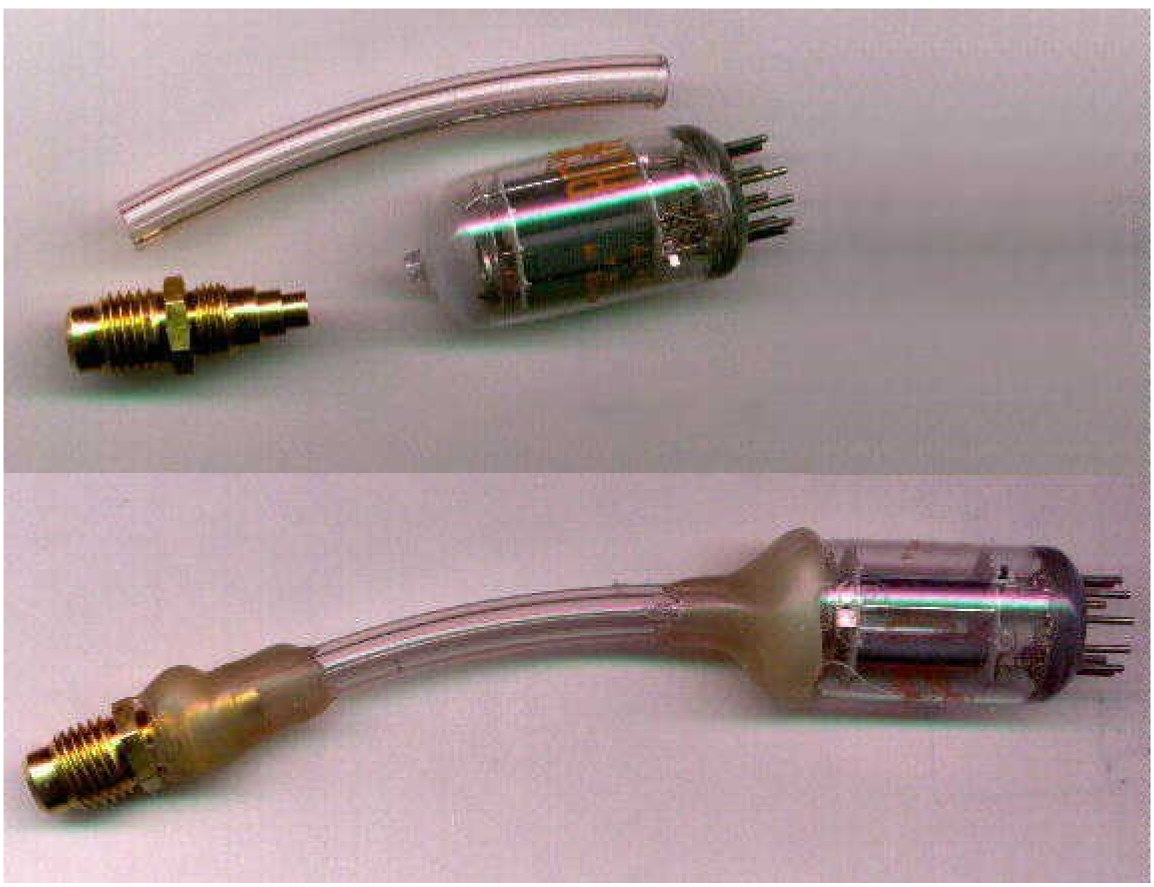
This simple oscillator can be heard through a nearby crystal set as a CW hetrodyne with incoming stations. In the tone modulated mode (S2 closed), morse code can be sent to a nearby radio by using a key in place of S1.

Vacuum tube operation at amateur grade vacuum.

Updated 8 June 2000.

I have found that a vacuum tube can operate at a vacuum level easily attainable by amateurs. We certainly are not talking about optimum performance, but rather an experiment to satisfy a life long curiosity about how high of vacuum is required to make a vacuum tube operate.

I had a couple of 5965 (equivalent to 12AV7) dual triode tubes and opened one to the atmosphere, let air inside and then attached a hose for connection to a vacuum pump. As the picture below shows, it was a simple operation. Notice how the normally mirror like getter (at the top of the tube) is now powdery white from being attacked by the air. It took roughly 30 minutes for the bright silvery film to turn white after breaking the seal on top of the tube.



The hose was glued on top of the tube with hot glue. The other end of the hose was attached to a 1/4" flare adapter with hot glue. Many sizes of clear vinyl hose such as that used here will collapse from atmospheric pressure. I used one with a thich enough wall to withstand

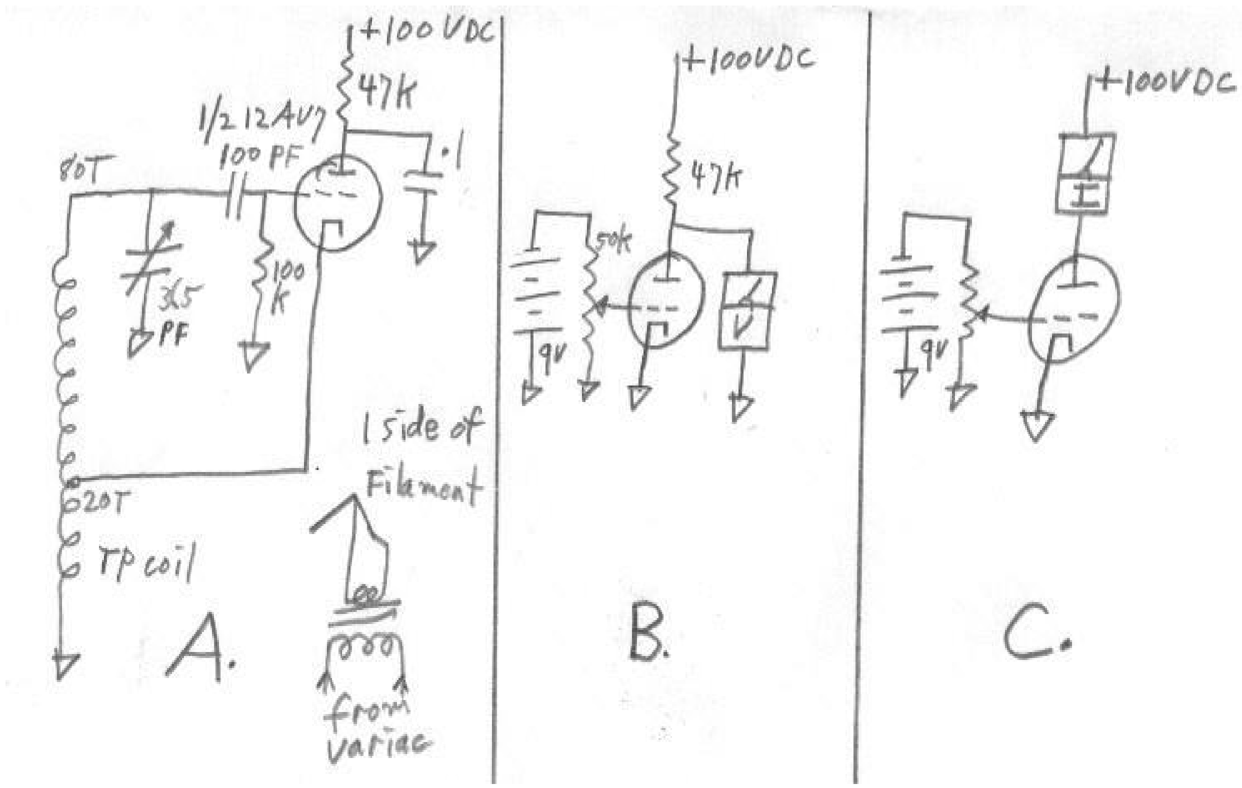
atmospheric pressure. The hot glue was a very handy way to go and it seemed to adhere well enough to the glass. It was surprising how long I could run the tube without melting the hot glue. It actually never melted, but I was careful not to run the tube for long periods.

The pump that I used is an old Robinair refrigeration service pump. I don't know how well hot glue is suited for high vacuum connections, but The pump is capable of getting down to 10 microns or below according to a Supcothermister vacuum gauge. A small degree of vacuum tube operation was observable at pressures as high as 1 torr but as expected, the tube worked much better at lower pressures of about 50 microns and below. Most of the experimenting described here was done at around 50 microns and below. When the vacuum was close to 10 microns, I would turn on the filament and notice an immediate climb in pressure from the hot filament outgassing. After several times of heating, however the vacuum would stay down.

The first attempt of observing vacuum tube operation was to connect the cathode and plate to an old Tecktronix 575 curve tracer. The grid was connected so that I could connect it to either the cathode, the plate or a biasing pot connected to a 9 volt battery. This tube is a double triode with a center tapped filament. This allowed operation of just one triode with 6 volts applied to one of the filaments. With the normal 6 volts across the filament, no glow was seen because of the air inside keeping it cool. As the pump was turned on, the filament started to glow, but maybe not quite so brightly as normal. Changes in current drain from the filament were very noticeable as the degree of vacuum changed and thus changed the temperature and resistance of the filament. This was observed simply by having a volt meter across the filament and watching the voltage change from a varying load. With a given voltage applied to the filament one might be able to build a good vacuum gauge by using a vacuum tube connected to a bridge circuit and a meter.

In order to observe any vacuum tube action at all, It was necessary to run the filament voltage much higher than normal - about 10 to 12 volts. According to the indications on the curve tracer, the tube seemed to be operating to a reasonable degree. One certainly would not expect full spec operation under these types of conditions. With 100 volt sweep on the plate and a 20k resistor, I was easily able to get a plate voltage change of about 40 volts from a 3.5 volt bias change on the grid. That seems to indicate a very usable amount of amplification.

The next step was to put my home evacuated tube to the real test by connecting it into an actual circuit such as an amplifier or oscillator. I did just that and had no difficulty in making a Hartley type broadcast band oscillator run with 9 volts applied to the filament. See schematic A. As the oscillator ran, I would turn off the vacuum pump and watch the oscillator signal on an oscilloscope as the pressure rose. Unbelievably, I could keep the oscillator running as the pressure rose to as high as one torr (1000 microns). The filament voltage had to be raised to 11 volts in order to keep it going at this pressure. The oscillator signal was much weaker at one torr, but it is fascinating that it could run at such high pressure in the tube.



I also connected it into an amplifier configuration and varied the grid input voltage swing while watching the plate voltage swing. See schematic B. I measured a voltage gain of about 15 or 16, a definitely usable gain.

Transconductance measurements were made using schematic C. The tube plate output current curve reflects positive as well as negative grid voltage. I only made transconductance measurements between zero and minus grid voltage. In this range the tube generally drew about 1 ma plate current using 100 volt plate supply. That didn't seem bad for a homepumped vacuum tube. Varying the grid voltage between minus 1.265 volts and minus .679 volts (.586 volt change) caused the plate current to vary from .5 ma to 1.5 ma. This calculated to be a transconductance of about 1700 micromhos.

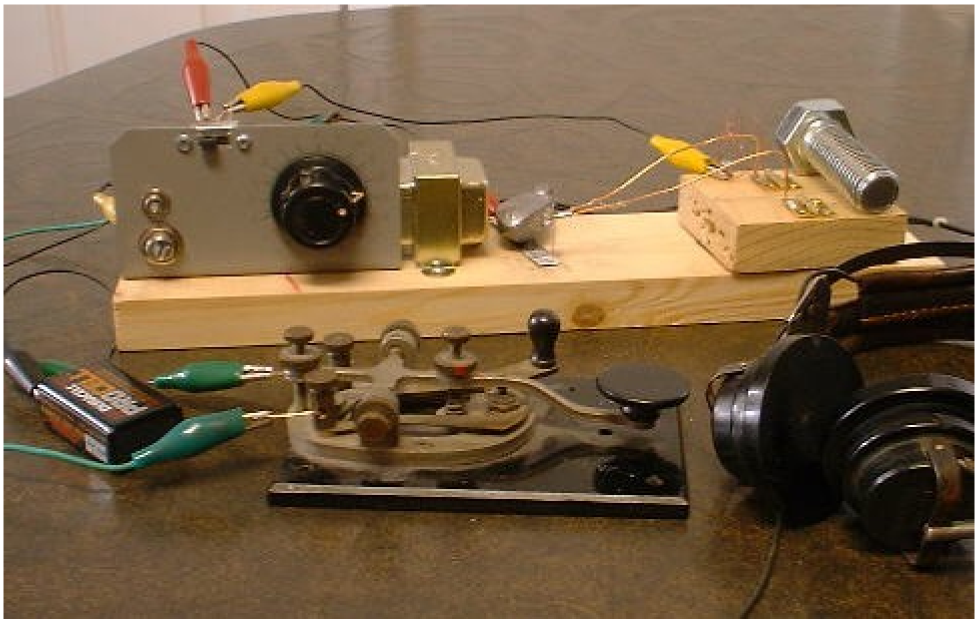
It may also be possible to make a vacuum gauge by measuring the plate conductance to the tube. Perhaps a versatile gauge could be made for two different ranges of vacuum by using the filament heat transfer method for one range and the plate conductance change method for another range.

The use of vacuum tubes, under the conditions described above, is a very adverse condition for the filaments. Four filaments became history in the course of the above experimentation.

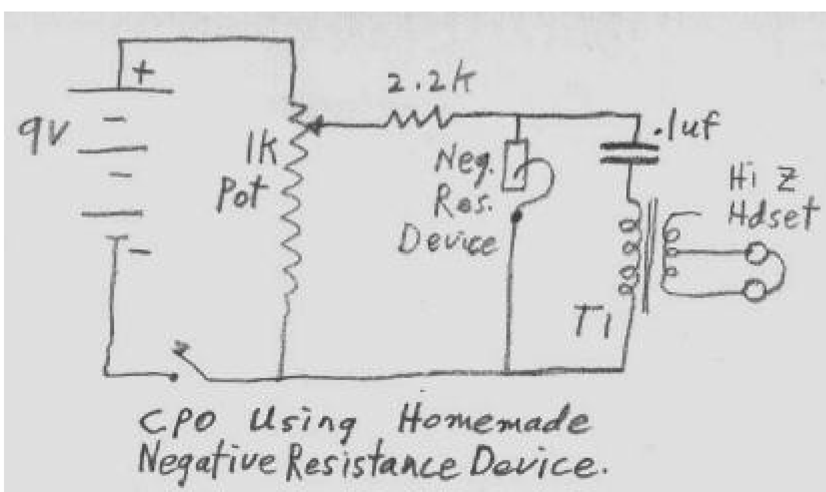
I hope soon, to try making a homemade vacuum tube completely from scratch. Even if it's operation is crude and has to have the pump running during its operation, it will be a very satisfying experience. It is something I have thought about all my life. The experiments described above make prospects for a crude homemade vacuum tube quite encouraging.

Code Practice Oscillator made from Homemade Active Semiconductor.

ByNyle Steiner K7NS 28 Mar. 2001



Code Practice Oscillator, also useful for testing homemade negative resistance materials.



Code Practice Oscillator Schematic. T1 is a small Radio Shack 12vac center tapped transformer. 12v winding connects to headset. 110v input winding is part of LC circuit.

This simple circuit is just like the Negative Resistance RF Broadcast Band circuit except that it uses an audio frequency LC circuit instead of an RF LC circuit. See Iron Pyrites Negative Resistance Oscillator Since writing the article on the iron pyrites oscillator, I have found a much superior way to make the negative resistance device. It is by heating a strip of galvanized sheet metal in a propane flame as described later.

Listening for a tone through a pair of earphones makes it easy to experiment with negative resistance materials without having to use a radio or any test equipment such as an oscilloscope or curve tracer. The heat treated zinc material seems to be the king so far for ease of use but I was even able to get audio oscillations from a heat treated piece of steel "music" wire. The procedure is to hunt around with the catwhisker at different pot settings until a tone is heard in the phones. A high impedance earphone is best as it tends to put less of a load on the circuit and thus increases the chance of getting oscillation. A low impedance load will work however, in fact; an 8 ohm speaker worked well and put out a faint tone that could be heard across the room.

Actual sound of Negatave Resistance CPO using heat treated galvanized sheet metal. (84K .wav file):

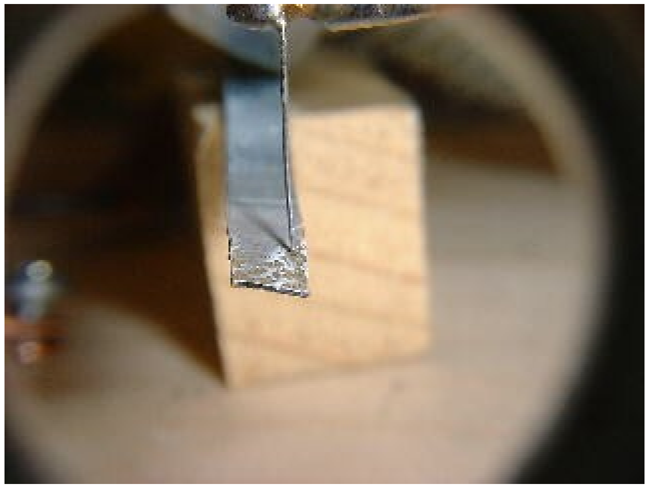
This circuit can easily produce RF frequencies in the AM Broadcast band if an appropriate LC circuit is connected in place of the audio one. Not all catwhisker settings that produces oscillation at audio frequencies, however, will oscillate at Broadcast band frequencies when switching LC circuits. It must be that different catwhisker settings can produce different bandwith capabilities. Nevertheless, it is very exciting to hear the audio tone that ensures that the negative resistance material is operating. A key in series with the battery makes this circuit into a good code practice oscillator. It is best however, to have the key mounted away from the oscillator, preferably on your lap or another table as the catwhisker is vibration sensitive.

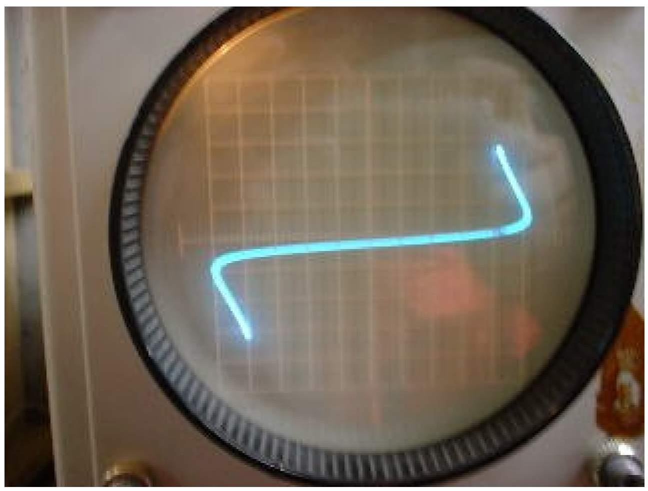
The negative resistance device was easily made by putting the end of a thin 1/4 inch wide strip of galvanized sheet metal, of the type used for furnace ducts, in the flame of a propane torch till it glowed bright red. It is a good idea to do this out of doors and to avoid breathing any of the smoke or fumes. People who are knowledgeable about welding say that poisonus fumes are produced when welding galvanized metal. After cooling, small dark spots would appear, especially on the side opposite where the flame struck. These dark spots are the main negative resistance areas. The catwhiskers tried were 28 gauge steel wire and 30 gauge copper wire. Both seemed to work well. The circuit (as with the iron pyrites) seems to be very forgiving as to the applied voltage level (pot setting).

As can be seen on the curve tracer, the curve can be quite symmetrical in both the negative and positive direction, although I sometimes would observe a more non symmetrical curve. It is also possible that applied dc could have some cumulative effect on the symmetry of the curve. This picture was taken while the curve tracer was applying ac to the device. I had to modify it so it could apply ac.

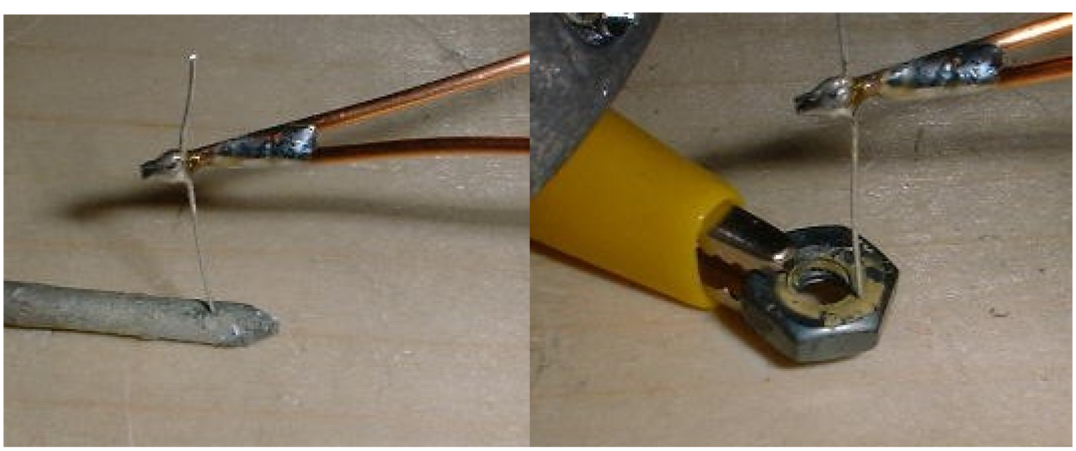
The oscillator circuit can be run easily from one 9v battery and it seems easier to obtain steady oscillation when the catwhisker is biased negative with respect to the metal strip. Some steady oscillation can be obtained however with the catwhisker positively biased.

Heat treated galvanized metal strip and curve produced.





Horiz = voltage 1v/div. Vert = current 1ma/div.



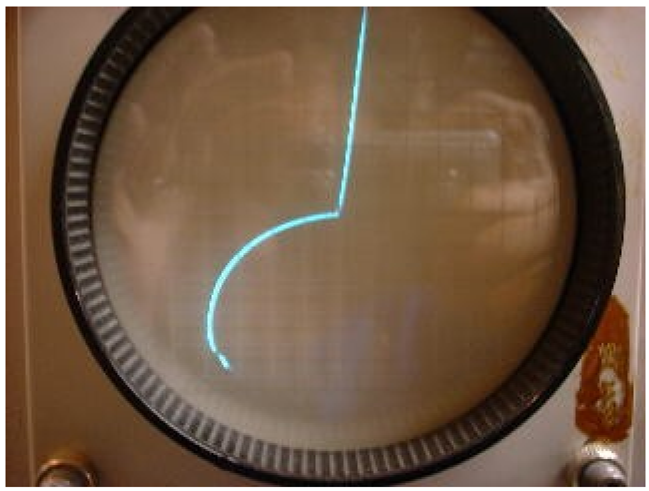
Heat treated galvanized nail and zinc chromate nut. Either can produce oscillations. Nail was somewhat difficult to adjust but nut was easy.

Normal catwhiskers seemed difficult to adjust so I built what I call a "Tone Arm Catwhisker" because of its resemblance to a phonograph tone arm. The idea of the Tone Arm catwhisker is to make it light and easy to move up and down, but rigid in sideways motion. This makes the catwhisker able to rest on slanted or round surfaces without sliding off. The sliding off aspect does not seem as important though when used on the flat strip of heat treated galvanized sheet metal. The picture of the Tone Arm is self explanatory; a triangular wire frame, a weighted base (with three felt bumpers on the bottom) and hinges to allow the arm to move up and down easily. The coil on the base is thin 30 gauge copper wire to make electrical connection to the arm without interfering with its delicate movements.

It seems that anything associated with zinc can make a negative resistance device. Even the heat treated galvanized nail can produce oscillations with careful adjustment. A heat treated zinc chromate 6-32 nut seemed to work very well and was very easy to adjust. I was able to get oscillations with somewhat more difficulty, using a heat treated strip of thin brass.

Iron Pyrites Negative Resistance Oscillator.

By Nyle Steiner K7NS 22 Feb. 2001



Iron Pyrites with #30 copper wire catwhisker. Curve tracer shows negative resistance in the reverse bias portion of the curve. Curve tracer is set at 2v/div. horiz and 2ma/div. vert. Curve tracer was modified to apply ac to the device.

Success with this experiment has been a very exciting experience for me as it represents the ability to build a simple homemade active semiconductor device. It is almost like making your own homemade transistor. This is an actual realization of some very old, and esoteric 1920's experiments, by W.H. Eccles, Greenleaf Pickard and Oleg Losev, that were so vaguely reported in a few articles that I have often wondered if in fact it had actually been done. Even so, I have always had an extreme fascination with those reports of being able to produce a continuous wave RF signal from a crude semiconductor matarial back in the very early days of radio.

My fascination led me to purchase an old Tektronix 575 curve tracer so I could study the curves of iron pyrites, galena and other detector materials that we normally play around with to make crystal sets. The 575 is a vintage but great tool because it continuously shows the curve in real time as you manually manipulate the samples. This is what is needed in order to make observations while manually touching a piece of wire to a piece of rock. I

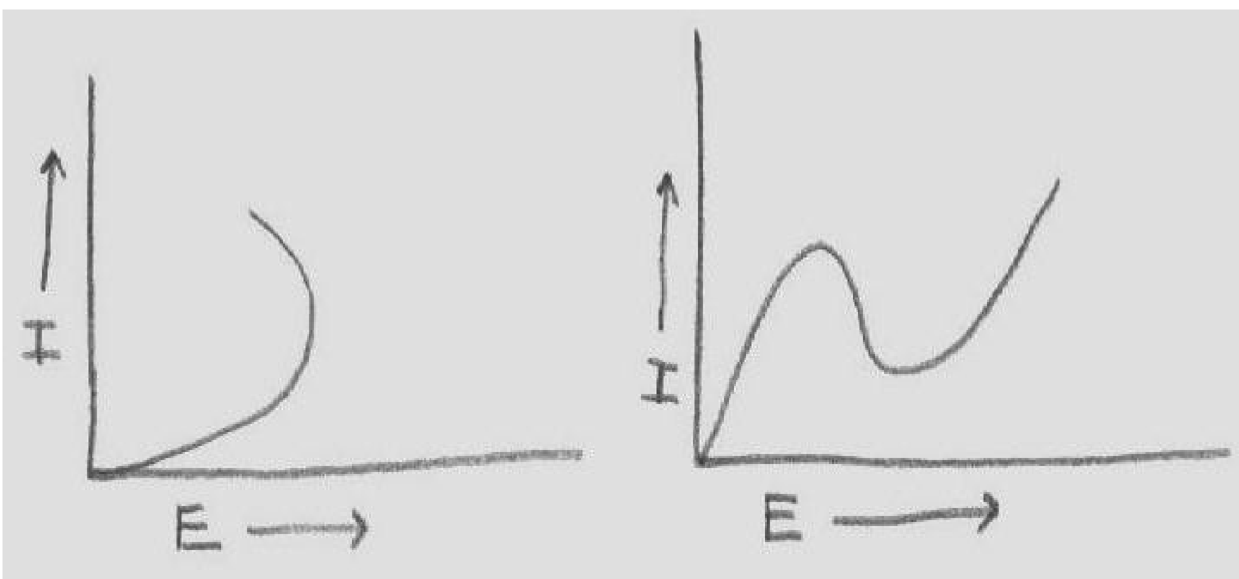
wanted to be able to display both the positive and negative portions of the curves simultaneously and so had to modify the curve tracer in order to do so.

Visable on the curve tracer, is a negative resistance curve that could be obtained from several different pieces of iron pyrites (with much finicky adjusting). Not all pieces of iron pyrites seem to work. I found that the kind with a lot of little crystal formations worked the best. The fact that several pieces that I happened to have, worked, makes it appear that a working crystal is not all that rare. It was nice to realize that this phenomenon was not just the result of some fluky "one in a trillion" find.

Adjustment of the catwhisker is very critical however, and requires a lot of patience in comparison to adjusting as a receiving detector. For every spot that produces a useable negative resistance, there are many many settings that would make an excellent detector for reception.

As the curve tracer photo above shows, the negative resistance region is in the reverse bias portion of the curve at approximately -8 volts and 8 ma. Some of the articles refer to this as being like a tunnel diode. It is true in the sense of having negative resistance, but it is in fact a different type of negative resistance. This is ok since both types of negative resistance can have the effect of gain, supplying enough energy to an LC circuit for it to become an oscillator. The negative resistance portion of the curve is obtained when negative voltage is applied to the catwhisker.

Two types of negative resistance.



Left is type found in iron pyrites. Right is type like a tunnel diode.

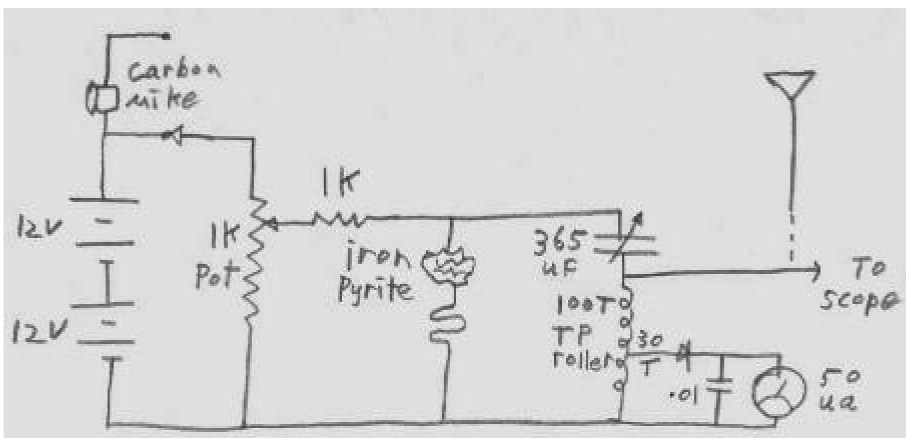
I am not an expert on negative resistance but I once read an article many years ago, that described how negative resistance is in two forms. I seem to recall them being a type S and a type N (I don't even remember for sure which is which. I welcome any enlightenment on this). One type is the type found in a tunnel diode and the other type is the type found here

and in other devices such as a neon lamp, unijunction transistor and what I believe to be in the old carbon arc oscillators. The figure above shows how the two types of negative resistance curves are possible. The negative resistance seen on the curve tracer is upside down with respect to that shown in the left part of the above figure so that both the positive and negative portions of the curve can be displayed.

The circuit shown is all that is necessary to produce a continuous wave signal in the broadcast band. It seemed difficult to get it to operate above 2mhz but was easy to get it running at anything below that, including audio frequencies. It seems to prefer certain LC ratios better than others. In the case of the broadcast band, A 365pf variable capacitor worked well with a 190uh coil (100 turns on a TP roller).

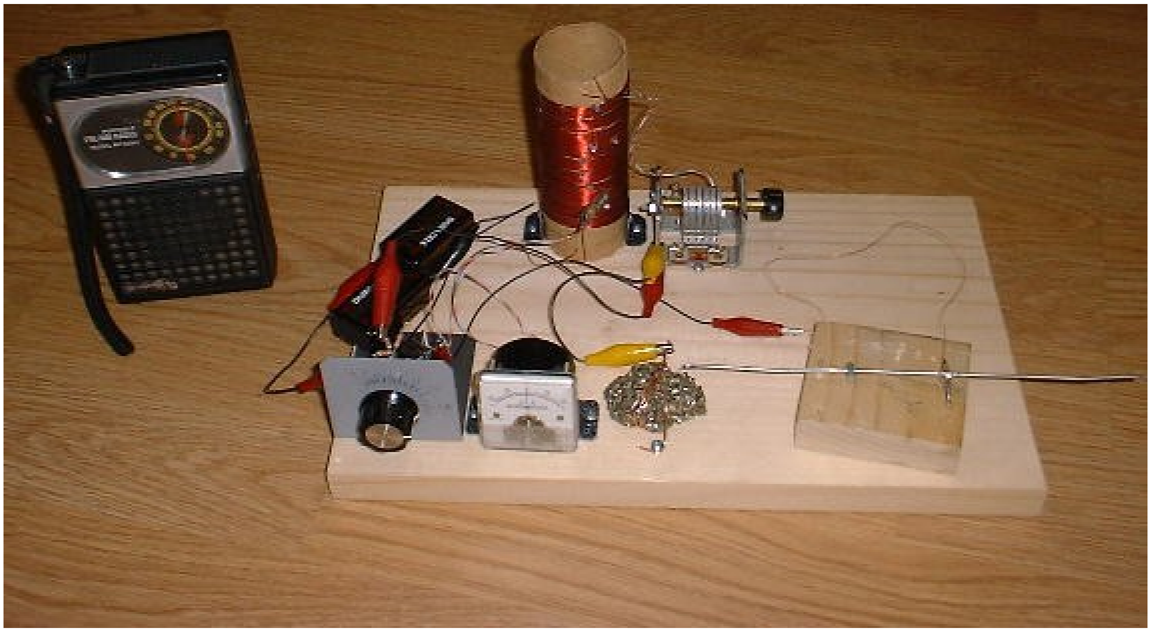
Once a good piece of iron pyrites is selected, the curve tracer is not necessary for making circuit adjustments. A meter or oscilloscope, to indicate that the the circuit is oscillating, is the most important tool in making circuit adjustments.

Broadcast band Iron Pyrites negative resistance oscillator.



Carbon Mike enables am broadcast to nearby am radio.

Iron Pyrites Negative Resistance Oscillator Board.

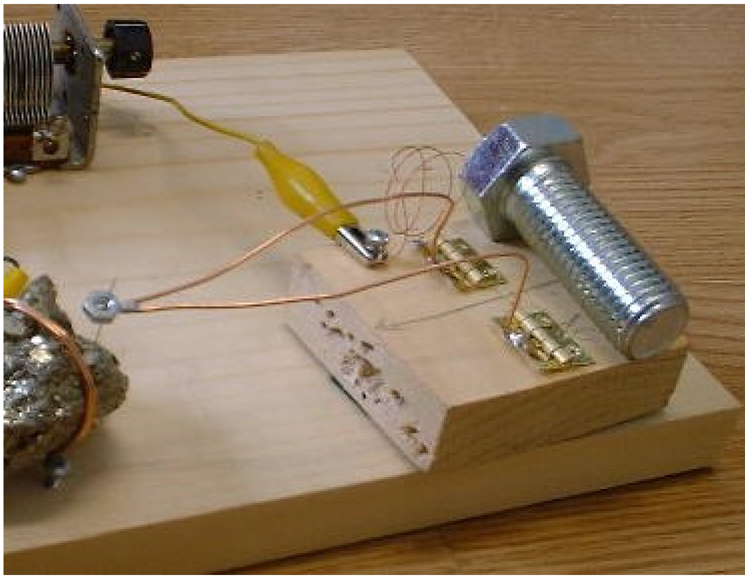
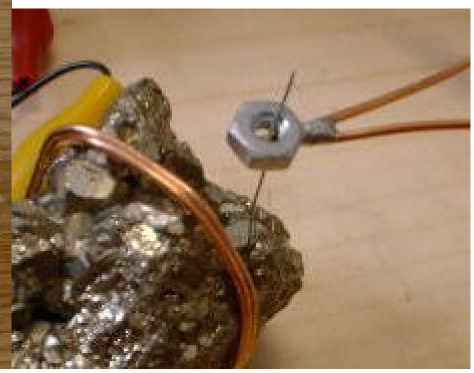


Circuit can run on 18 volt supply (two nine volt batteries). Note "Tone Arm" catwhisker.

When adjusting the 1k pot, I could find a range where the oscillation amplitude would vary with the voltage from the pot. This suggested the possibility of voice amplitude modulation with a carbon microphone. I was indeed able to hear my voice on a nearby radio with a carbon microphone placed in series with the battery supply. Just imagine the fun it was to be able to talk on the radio with an electrified crystal set.

I found it extremely difficult to get steady oscillations with conventional type catwhiskers. I tried a simple idea that I call the "Tone Arm" catwhisker because of it's resemblance to the tone arm of a phonograph. With it I can often obtain steady oscillations that last indefinite periods of time (several minutes anyway). This catwhisker also worked very well when used with a normal crystal set. I got good results using #30 gauge copper or #28gauge steel wire for the catwhisker. Those sizes are what I happened to have handy.

"Tone Arm" catwhisker close views.

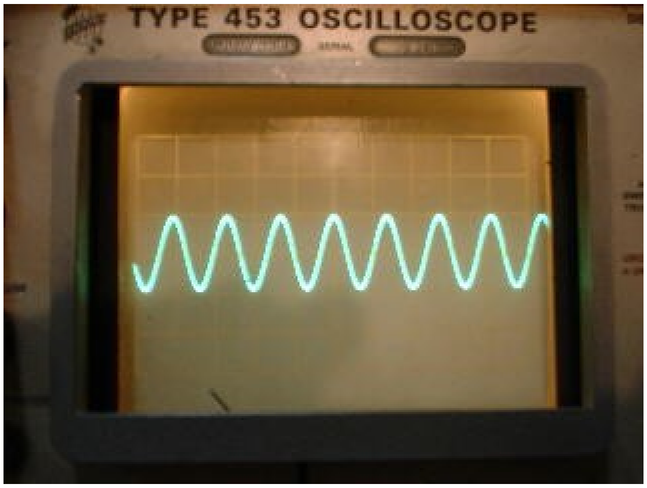
This closeup is an improvement over the tone arm seen in the oscillator board picture above.

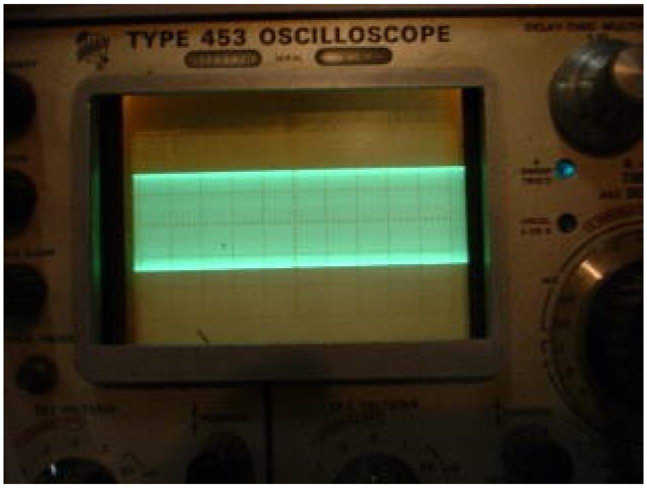
The idea of the Tone Arm catwhisker is to make it light and easy to move up and down, but rigid in sideways motion. This makes the catwhisker able to rest on slanted crystal facets without sliding off. The picture of the Tone Arm is self explanatory; a triangular wire frame, a weighted base (with three felt bumpers on the bottom) and hinges to allow the arm to move up and down easily. The catwhiskeritself, can be any chosen piece of fine wire connected to the end of the arm, by wrapping or soldering, and pointing downward. The coil on the base is thin 30 gauge copper wire to make electrical connection to the arm without interfering with its delicate movements. A small weight can be put on the end to increase catwhisker pressure.

To connect to the iron pyrites, several turns of bare #18 copper wire were wrapped around it and twisted tight. I have always found this kind of arrangement to be as good as anything. It has never seemed that casting in molten metal etc. is at all necessary for any of the crystals I have ever experimented with. Another copper wire over the crystal and wrapped around a couple of screws in the board works well for mounting the crystal.

The best way to get the circuit going is by setting the 1k pot to a mid point and then patiently and carefully probing with the catwhisker. Catwhisker adjustment is by far the most critical part of the process. Many points will be found where the meter will jump momentarily. These are good places to stop and try some fine adjusting, by gently nudging the wood block that supports the "tone Arm", for a steady meter indication. If nothing happens, the pot level is raised a bit and searching on the crystal continues. The ranges on the pot that work are fairly wide in relation to the complete range of the pot. This puts most of the burden of adjustment on simply searching the crystal. Use just the oscillation indicator for adjusting. Get the circuit oscillating and then tune it to a selected frequency on a nearby radio. Trying to adjust by listening to the the radio is futile because you would have to search the crystal for each of many many different tunings as well as each of many different pot settings. You can imagine how many combinations would have to be tried.

Scope picture of signal from Iron Pyrites Oscillator.





A clean continuous sine wave is attainable with careful adjustment. Many adjustments however, produce a somewhat distorted sine wave. Frequency shown is approx 700 khz.

Do not sell your expensive radio just yet. This circuit is far from being a replacement. It is extremely finicky to adjust and is not great for staying in adjustment. However, I can usually find a setting where the circuit can be run for a number of minutes while I walk away and do something else. The biggest feature this circuit has to offer is the thrill of watching it run.

See also Zinc negative resistance device. Zinc Negative Resistance. See also homemade Tunnel Diode N type device. Homemade Tunnel Diode and RF Oscillator.

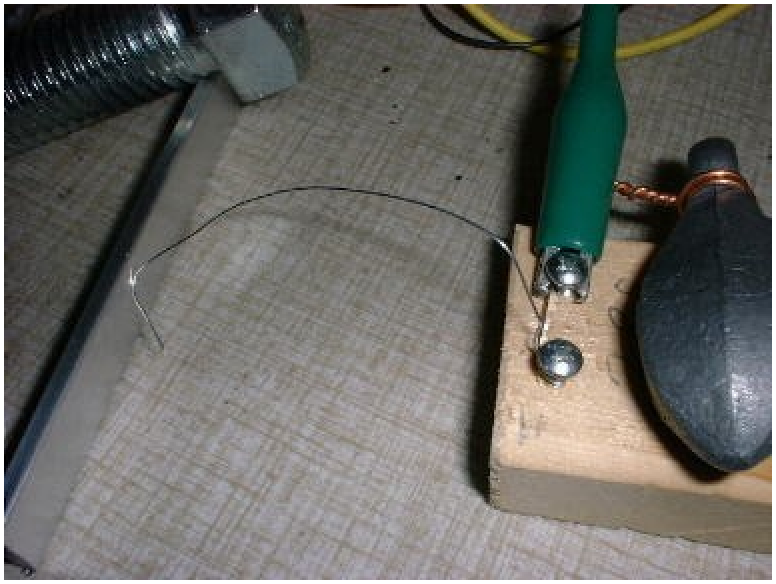
Negative Resistance Oscillator with Homemade Tunnel Diode.

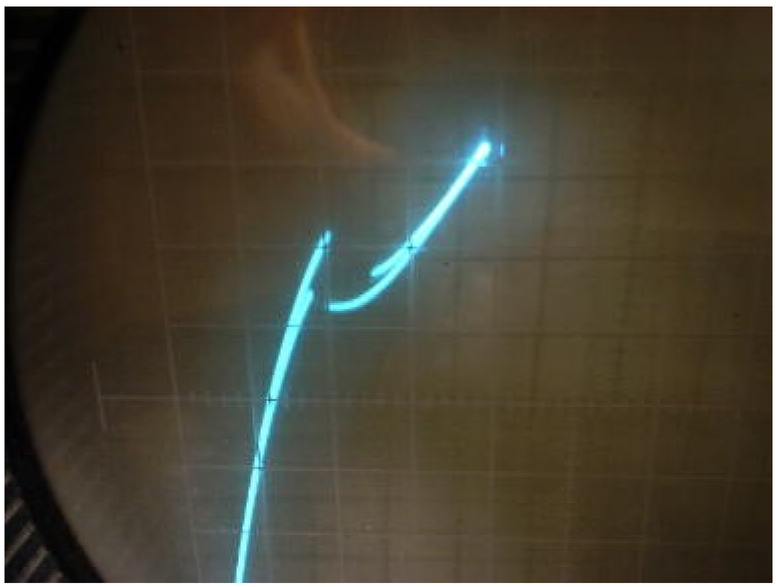
By Nyle Steiner K7NS May 9. 2002

Updated March 2003

I have found that it is easy to make an N type negative resistance device, similar to a tunnel diode, by lightly touching a piece of #28 galvanized steel wire against a piece of aluminum. This project may not be very practical but I find it to be a very exciting experience. When I first heard about tunnel diodes many years ago, they seemed to me, to be one of the most exotic devices on earth. It was very exciting to discover that I could easily make at home, at least in very crude form, an actual working device that is similar.

Home made device similar to a tunnel diode and curve produced.





N type negative resistance device, made simply by lightly touching the side of some #28 gauge galvanized steel wire to a piece of aluminum. Curve tracer was set at 5ma per division (vertical) and .1 volt per division (horizontal). Notice the peculiar hysterisis like loop at the negative resistance point. The device seems to respond in this way to the wide bias voltage excursions from the curve tracer. This does not seem to be a problem when applying a steady bias from a low impedance dc source.

A similar project, but using S type negative resistance instead, was sucessfully done earlier using iron pyrites or a heat treated piece of galvanized sheet metal. The heat treated sheet metal device, being an S type negative resistance device, is much different than the device described here, and operates in a much higher voltage region.

[Iron Pyrites Negative Resistance Oscillator](#)
[Zinc Negative Resistance Oscillator](#)

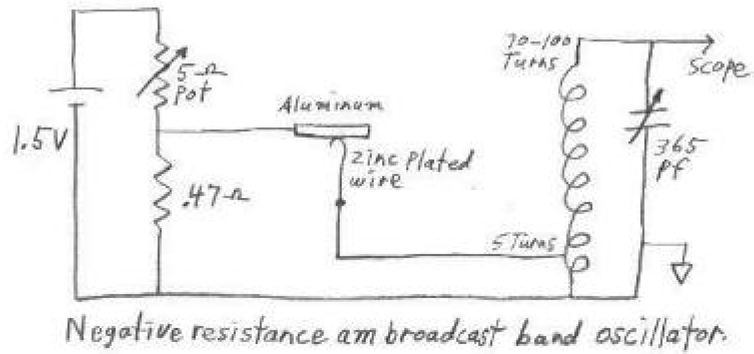
I am guessing that the natural zinc oxide layer that forms on the wire may be responsible for the negative resistance of the device described here. The voltage level where the negative resistance happens is fairly consistant and is almost always between 200 and 250 millivolts. The current level where it happens however, can vary widely between 20 and 100 milliamps.

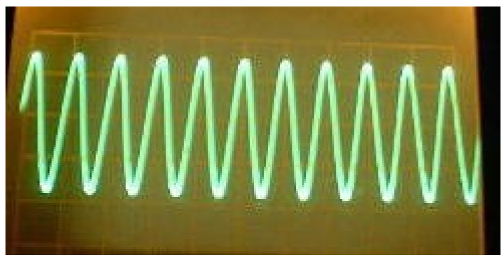
This circuit can be easily powered from a 1.5 volt battery. One characteristic of N type negative resistance devices is that they typically require a very low bias source resistance in order to keep the bias voltage stable within the negative resistance region. With too high of bias resistance, the voltage, as it enters the negative resistance region, will have a tendacy to suddenly jump past it. This is why a gap is seen in the curve (see photo). This homemade device, with its narrow negative resistance region, requires an even lower bias source resistance than a typical tunnel diode. A typical tunnel diode can be biased within the negative resistance region with a bias resistance of around 20 ohms. This device works best when the bias resistance is 1 ohm or less. Unlike this N type device, S type negative resistance devices, such as the heat treated galvanized sheet metal device, act in the opposite way and bias stability is best with a higher bias source resistance.

This device, like many others that I have been making, has a symmetrical curve in both the positive and negative direction and can work with the battery connected either way. Just for the sake of being consistant, I did most experimenting with the aluminum biased positive with respect to the zinc covered wire.

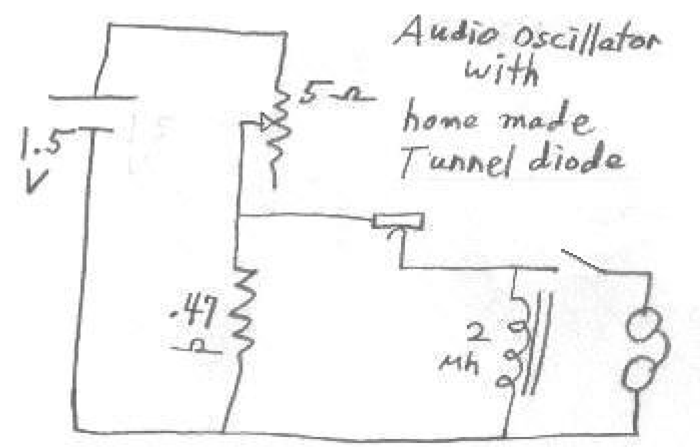
The low (approx 250 millivolt) bias voltage for this device was produced across a .47 ohm resistor, connected to the battery through a 5 ohm pot. This means drawing 500 to 600 milliamps from a 1 1/2 volt battery in order to supply approx 35 ma to the device. A 5 ohm pot is not as common as a 50 k ohm pot but can be easily obtained at a surplus outlet. It might also be easy to improvise a 5 ohm pot from something like a pencil lead. It was easy to run the circuit from a single AA cell but of course a D cell is much more suitable when drawing this much current. An emitter follower circuit could be a much more efficient way to bias this device but I like to have this circuit completely void of any commercially made transistors or other active devices. I wanted to be absolutely sure, that this homemade device is indeed what is actually producing the oscillations. Below are schematics and waveform pictures of an LC oscillator and a relaxation oscillator.

Negative resistance LC oscillator from homemade tunnel diode.





Negative resistance relaxation oscillator from homemade tunnel diode.



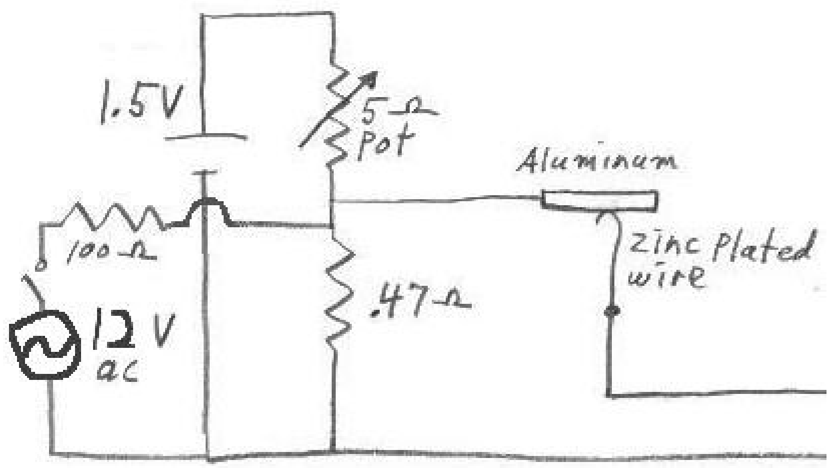
This relaxation oscillator can be made to run at any frequency from audio to 12 mhz by changing the value of the inductance. A headset of any impedance can be used at audio frequencies to make adjustment easy. The switch can be a key for use as a code practice oscillator.

Adjustment of these circuits can be tricky but easily done if things are set up rite. I have had very little success in getting the circuit to oscillate while trying to adjust just the catwhisker with a set bias voltage. The easiest and best way to adjust this circuit is to switch the device out of the circuit and to a curve tracer. Adjust the catwhisker until you observe a negative resistance region, similar to that shown in the picture above, and then switch the device back into the oscillator circuit. The bias pot is then adjusted, looking at an oscilloscope, for a clean oscillation signal. The circuit above, for the sake of reducing clutter, does not show a dpdt switch that I sometimes use to switch the negative resistance device between a curve tracer and the oscillator circuit.

A curve tracer is not always a handy thing to have around. The circuit can also be easily adjusted by using just an oscilloscope and a 12 volt transformer, as shown in the partial diagram below. While the normal dc bias is applied and adjusted to approx 200 to 250 millivolts across the .47 ohm resistor, 12 volts ac from a transformer can be switched into the circuit through a 100 to 200 ohm resistor. This applies a varying dc bias to the negative resistance device. The catwhisker can then be adjusted until you see 60 cycle bursts of rf on the scope. If the ac voltage is now switched off, a continuous oscillation can usually be achieved by watching the oscilloscope and adjusting the bias pot. The circuit will then be running entirely from the 1-1/2 volt battery.

The audio frequency oscillator can be easily adjusted without an oscilloscope or curve tracer by simply connecting a pair of headphones across the inductor. The temporary application of the 12 volts is still helpful.

Using 12v ac to adjust oscillator without the need for a curve



tracer.

I have had some success in getting the circuit to run without the use of a 12 volt ac source or curve tracer by connecting an analog volt meter (250 mv full scale), across the .47 ohm resistor. With some practice, it is possible to adjust the catwhisker while watching the voltage and then adjust the bias pot until you get oscillations on the oscilloscope. An analog volt meter is usually better than a digital one for applications like this because you need the instant response of the needle while making adjustments. A volt-ohm meter set to read on the 50 microamp scale will usually suffice as a low voltage (around 250 millivolts full scale) dc volt meter.

So far, it is easy to get a continuous sine wave signal at 1 mhz. The amplitude of the oscillation is typically between .35 to 1 volt pp. Few things can beat hearing a hetrodyne on a radio receiver that is the result of a homemade active device.

With the am broadcast band LC circuit, the signal is usually a nice looking sine wave with the frequency being adjustable across most of the am broadcast band by turning the variable 365 pf capacitor. The coil is 100 turns of .034 dia. enamel covered copper wire on a piece of 1-1/2" abs pipe (1-7/8" outer diameter). Taps were placed at 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, and 90 turns. As shown in the diagram, the very low impedance of the device worked best into the 5 turn tap. The variable capacitor was connected to between 70 and the full 100 turns of the coil.

In trying to produce higher frequencies of the order of 7 mhz, I substituted an LC circuit with a smaller inductance coil. While using this higher frequency LC circuit, the long sloppy clip leads used to build the circuit, were a much greater factor in determining the frequency than the LC circuit was. By taking the LC circuit out and substituting it with just varous sized inductors or even just pieces of wire, in series with the negative resistance device, a relaxation oscillator was made. This relaxation oscillator could be made to run anywhere from audio frequencies to (with careful coaxing) 12 mhz, depending on the size of the inductance in the circuit. The higher frequencies were produced just by putting various lengths of the wire in series with the device.

The only limitation on the lowest frequencies attainable with this relaxation oscillator, seems to be the internal resistance of the inductor. Big inductors tend to use more wire and thus have a higher resistance. With this circuit requiring such a low bias resistance, one ohm is close to the maximum internal resistance that is usable in an inductor. The inductor for audio frequencies should therefore be made with as few turns as possible and as large diameter of wire possible into a toroid core with a high permeability. A typical inductance for attaining audio frequencies with the above relaxation oscillator, is 2 mh.

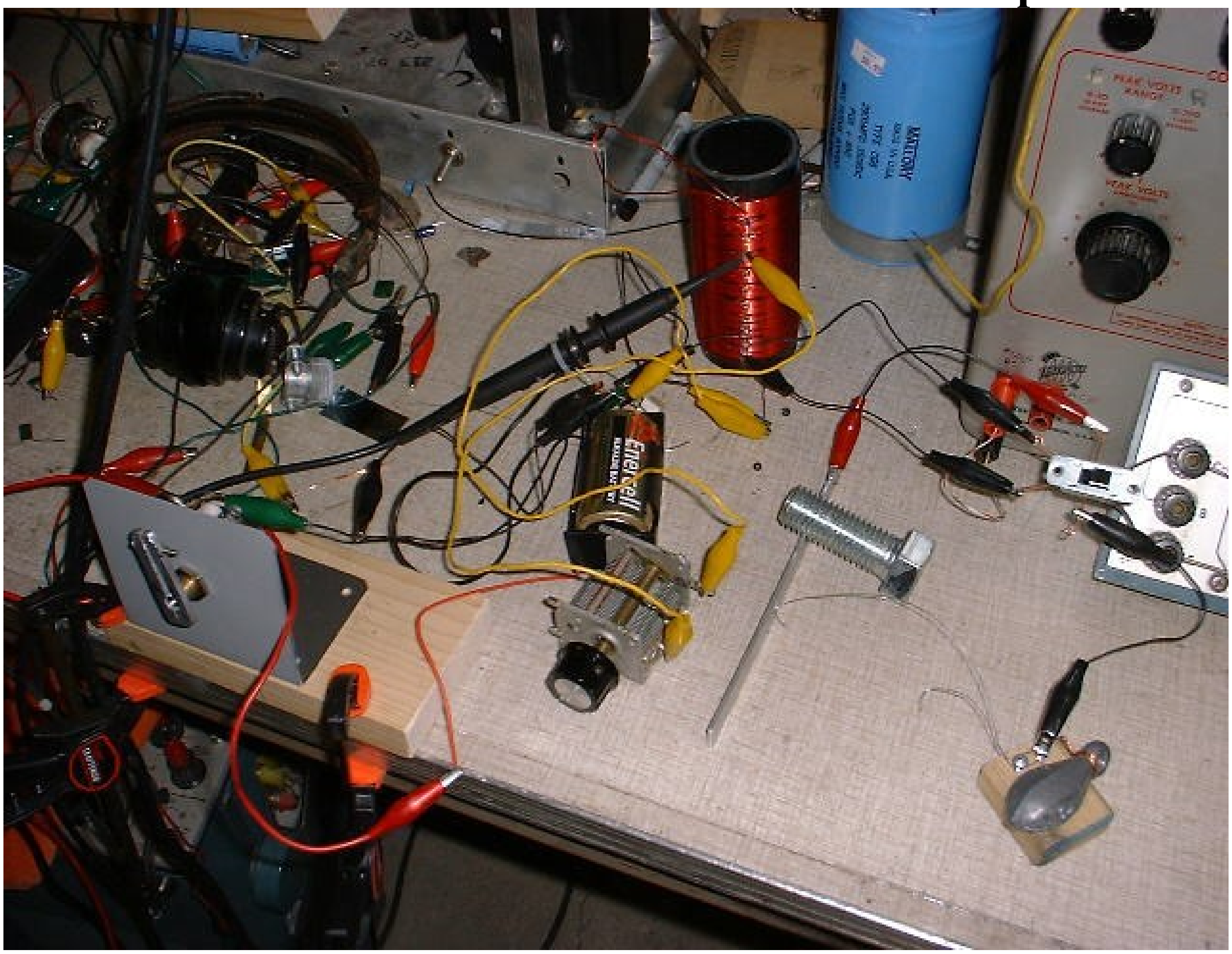
The negative resistance part of the curve can form at many different current levels. With the relaxation oscillator, negative resistance at higher current levels seemed to produce lower frequencies. This is probably because the overall resistance across the inductor, is lower when the negative resistance is at a higher current level.

A good catwhisker arrangement can be made by putting two screws into a piece of wood about 1-1/2" square near the edge. A piece of #28 gauge galvanized steel wire can be wrapped around the two screws and cut to about 4 to 6 inches in length. A heavy weight on the block will make its position stable after making adjustments. This N type negative resistance device worked well by bending the tip of the wire around so that the zinc plated side of the wire, instead of the tip, touches the aluminum.

Several different pieces of zinc from different sources, in addition to the galvanized wire, were tried and they all seemed to work for making the negative resistance. I also had

success using different pieces of aluminum from different sources. None of the pieces of aluminum were anodized. I was even able to get the circuit to work after buffing the aluminum and galvanized wire with a piece of "Scotchbright" like material. No special treatment or heating needed to be done to either the zinc or aluminum. The aluminum and the galvanized steel wire were used in their original condition.

Homemade tunnel diode and oscillator circuit setup on table.



Negative resistance oscillator circuit can be seen in the foreground. Notice the dpdt slide switch used to switch the negative resistance device between the curve tracer (right of picture) and the oscillator circuit. The extra stuff in the background is not part of this project. A crude knob had to be improvised from a piece of aluminum in order to easily turn the 5 ohm pot which had only a screwdriver slotted shaft less than 1/8" long.

Carbon Arc RF Oscillator.

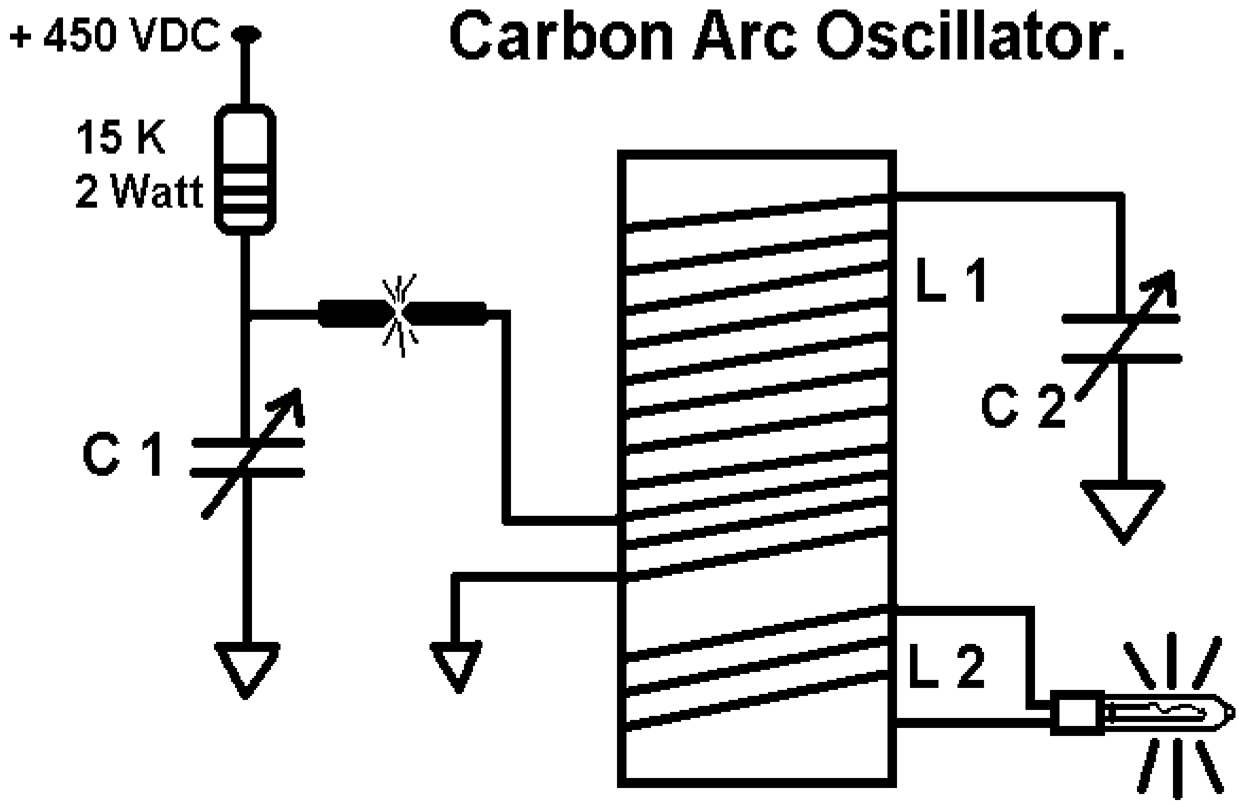
Caution must be exercised when working with the high voltage and circuit shown here. In addition to the shock hazard, this oscillator generates a lot of RF energy and noise. It should only be used to light the lamp. Connection to any antenna or long wires should be avoided. It is illegal to use this circuit for any kind of signal transmission.

The carbon arc oscillator is a crude form of "CW" oscillator and was actually used in the early days of radio to transmit AM voice before the vacuum tube came into wide use.

The carbon arc can be made by using a couple of pieces of mechanical pencil lead. Almost any size will do. I arbitrarily used HB hardness and tried several sizes. They all worked well, but the larger size seemed to be more stable. The power supply can be from an old tube radio or amplifier, or it can be built using rectifier diodes and 50 microfarad electrolytics capable of operation at 500 vdc. L1 can be 100 turns of enameled copper wire with a tap at every 10 turns. A good place to make the tap for the arc is about 20 to 30 turns. The top of the coil can be tapped anywhere from 70 to 100 turns. L2 which drives the lamp, is a separate coil of 8 turns of vinyl insulated wire wrapped around the outside of L1, near the ground end. The lamp used was a small 4 volt christmas tree lamp. C1 & C2 are 360 pf variable capacitors from old radios.

The setup that I made was very crude, but functionally, lived up to all of my expectations. The two pieces of lead were held in aligator clip leads and held together by hand. It is a good idea to mount the high voltage side carbon to the table and just hold the ground side carbon to avoid getting shocked. The two leads are touched lightly to start the arc and then held a small fraction of a millimeter apart to sustain the arc (which is sometimes difficult). If the arc is done carefully, the lamp will glow brightly, indicating the presence of some real RF energy.

The carbon arc transmitters were supposed to have worked on a principle of Negative Resistance from the carbon arc and indeed, they resemble oscillator circuits built around a tunnel diode. The circuit shown was built in an attempt to reproduce and observe the negative resistance characteristic of the carbon arc. Close examination of this circuit, however, seems to indicate that it is actually operating as a relaxation oscillator - much like the ones built with neon bulbs (but much more potent !!). C1 charges up to a voltage high enough to re-ionize the carbon arc and then discharges through it and part of L1, feeding L1 & C2 with a pulse of energy. An oscilloscope across C1 shows a sawtooth waveform. Using a 365 pf variable capacitor, the relaxation frequency can easily be adjusted to a frequency above 1 mhz. The arc transmitters of a past age had numerous refinements beyond what is shown here and this experiment does not necessarily discredit the negative resistance explanation of their operation.



Jet Negative Thrust by Sucking???

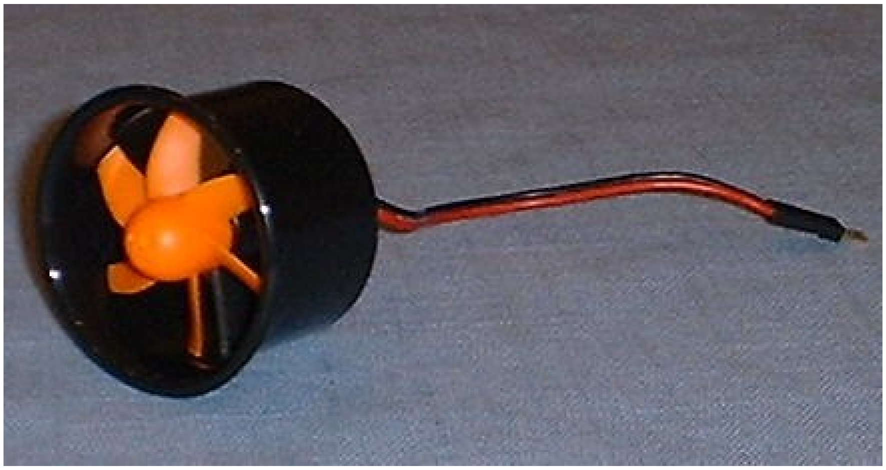
ByNyle Steiner K7NS 18 Aug 2003.

The issue has been raised as to whether forward thrust can be obtained by sucking in through the front instead of blowing out the back. Feynman talks about a water sprinkler that spins from water shooting out its ends but does not spin if it is submerged in water and water is sucked into it (Search google with the words - Feynman water sprinkler). From experiments that I have done and described below, there appears to be a very simple rule. When you blow out a tube, you get positive thrust; when you suck in through a tube, you get very little or no negative thrust at all in the opposite direction. The amount of negative sucking thrust that I could observe from my experiments, was essentially zero. My thrust measuring capability however, was not sophisticated enough to make very fine measurements.

One of my friends who is a master degree research physicist, also found this experiment to be very intriguing.

This is why the pop pop boat can produce thrust. It repeatedly pushes water out a tube and sucks it back in again. It gets its thrust every time the water is pushed out but gets essentially zero negative thrust when the water is sucked back in.

Ducted Fan and U Tube Construction.



U tube construction with electric ducted fan in upper picture. The tubing is 1 1/2" abs pipe. The long ends are 12" in length. The ducted fan is EDF-40H and is sold by GWS.

I decided to build a U shaped tube with a ducted fan in the middle. All air that blows out one end must be sucked in from the opposite end. The motor was run from two series lithium ion cells taped to the side of the tube. The tube with the ducted fan was suspended

from the ceiling with two 5' 4" strings near a flat surface that could be marked to show amounts of deflection from thrust.

By having both ends face the same direction, any forward thrust observed would indicate that the blowing end was pushing more than the sucking end was pulling. This turned out indeed to be the case.

U Tube Jet.

Left, the U Tube is hanging idle. Note mark by end of tube. Right, thrust is clearly shown by deflection away from the mark. Positive thrust at the blowing end is not cancelled by negative thrust at the sucking end.

What is the difference in thrust when the intake is facing forward instead of backward?

The ducted fan was later mounted at the intake end of the tube as shown in the pictures below. Deflections were observed with the intake facing toward the back and with the intake facing forward. It turns out that no significant difference in thrust was observed. In fact, in at least one instance of observing closely with another person present, the thrust (deflection)surprizingly, was slightly greater when the intake was facing backward (same direction as the output end). See pictures below.

Comparison of thrust with intake forward and backwards.

First picture, jet is idle. Second picture, jet is running with intake backwards. Third picture, jet is running with intake forward. Casual observation shows thrust (deflection) to be essentially the same in both cases.

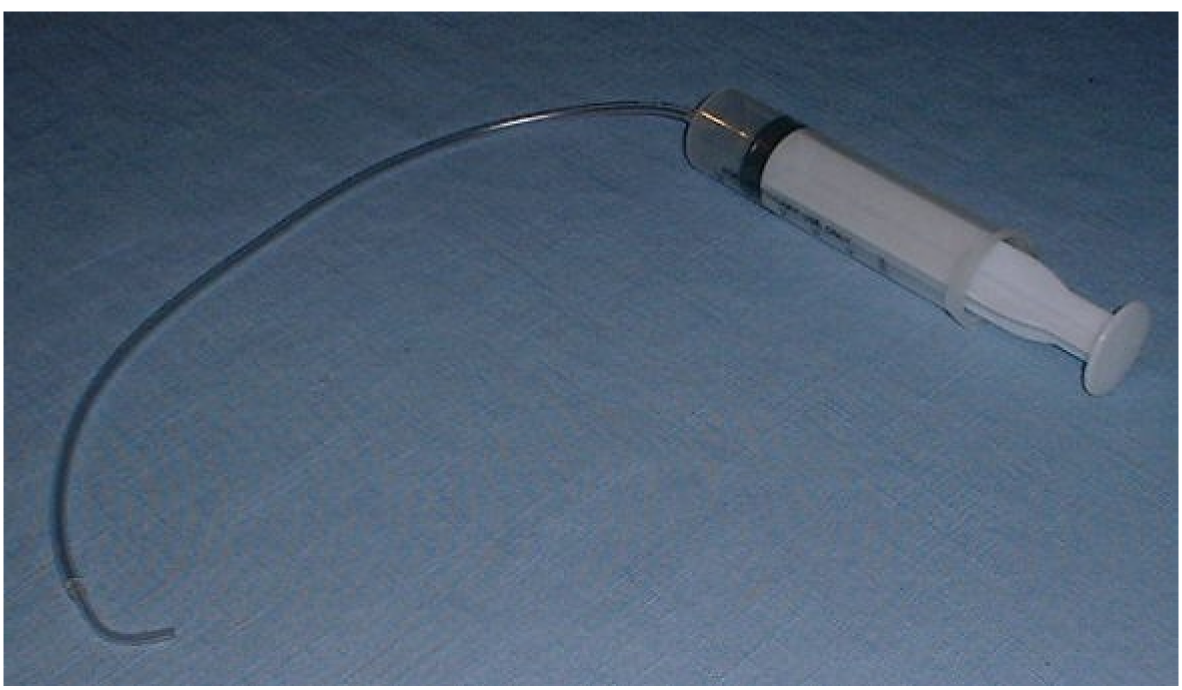
How much negative thrust when the output end faces downward?

So far, we have been looking at the results of the intake negative thrust working against the output positive thrust. With the output facing straight down, it's effect is completely removed and any thrust or deflection sideways to the right would be an indication of negative thrust from the intake. The result in this case; no negative thrust or deflection was observed. See pictures below. Much thrust was observed when the ducted fan was reversed making the end pointing down the input and the horizontal pipe the output.

Effect of sucking input alone with output facing downward.

First picture, jet is idle. Second picture, jet is sucking into horizontal pipe but no observable negative thrust (deflection). Third picture, Ducted fan has been reversed and jet is blowing out horizontal pipe. Much positive thrust (deflection) is observed.

Same results were observed using a plastic tube hanging from a syringe.



With tube hanging and the syringe held in a steady position, much thrust was observed when the piston was pushed into the syringe. No noticable tube movement was observed when the piston was pulled.

The same results are observed by filling the syringe and tube with water and putting the tube under water. I did notice with water that there is a small (fraction of a second) momentary deflection of the tube when the piston is first pulled. After that, the tube appears to have no movement at all. This effect probably has something to do with initially getting the water in motion. When the piston is pushed, the tube moves energetically as long as water is being pushed through it.

My first impression, when reading about the Feynman sprinkler (which was erroneous) was that a high pressure can be pushed out; but, only one atmosphere can be sucked in,therefore much more thrust can be produced by pushing air out the tube. This is not the case as I could observe thrust by blowing my breath through the plastic tube and I know that I can not come even close to producing one atmosphere of pressure with my breath. I was able to suck much more pressure with the syringe than I could ever blow. My blowing produced much more thrust or movement than the essentially zero that I could get by pulling on the piston of the syringe.

Another explanation (which I find inadequate) for this lack of negative thrust when sucking in is as follows. When air or water is sucked into a tube, it enters from all directions. When air or water is blown out a tube, it shoots out in a concentrated stream in one direction. One would expect that even though air or water is coming in from all directions, there would still be a percentage coming straight in that would at least create a lesser but observable amount of negative thrust. With this experiment we are observing zero negative thrust.

I do not claim to have a better explanation for these observations but would suggest that the lack of negative thrust from the intake may be because air or water can flow into the intake so readily that a lower pressure outside the intake can not form easily. There is no pressure differential between the intake and the outside air or water. Air will always tend to expand into any sucking input and maintain atmospheric pressure. No thrust is produced because there is no pressure differential. Imagine trying to pull yourself forward by pulling on a large compressed spring that is expanding toward you. When a piece of flat cardboard is held very near the intake however, negative thrust is finally observed and the tube pulls toward the cardboard. This may be because the cardboard impedes the air flow into the area very near the end of the tube and a lower pressure now forms between the intake and the cardboard. Imagine the intake just fitting inside a closed cylinder. Lower pressure would certainly form inside the cylinder and the intake tube would thrust itself into the cylinder. One might wonder if in this experiment, a much greater velocity of air flow might produce a more observable amount of negative thrust.

When blowing out, there is a definite pressure differential between the output and the outside. This would create positive thrust.

Simple Homemade Thermistor and Pressure Sensor.

ByNyle Steiner K7NS 12 Sep 2003.

Homemade Thermistor and Pressure Sensor.

A thermistor can be easily made using copper oxide. Two clean copper wires were mounted on a board as shown in the picture above. One or both of the wires were heated red hot in a propane torch while separated. After cooling the wires were adjusted so that they lightly touch. An ohm meter connected between the two wires would measure a high resistance (typically 40 to 100k). Holding a flame under the point where the two oxidized wires touch, can make the resistance fall to 1k or less. After the heat is removed the resistance will rise back to the original high value.

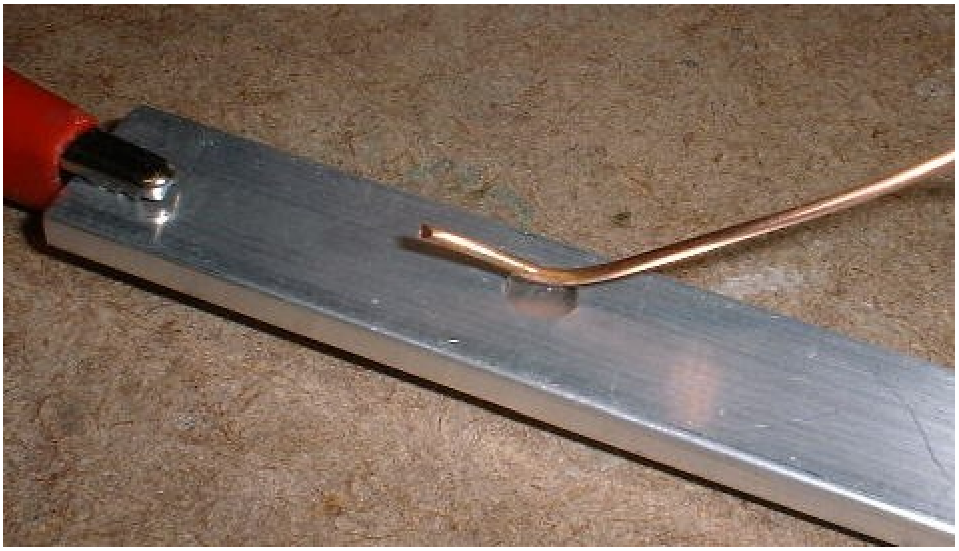
This simple homemade device can also be used to sense pressure. Squeezing the two wires gently will make the resistance reading on the ohm meter drop in proportion to the applied pressure.

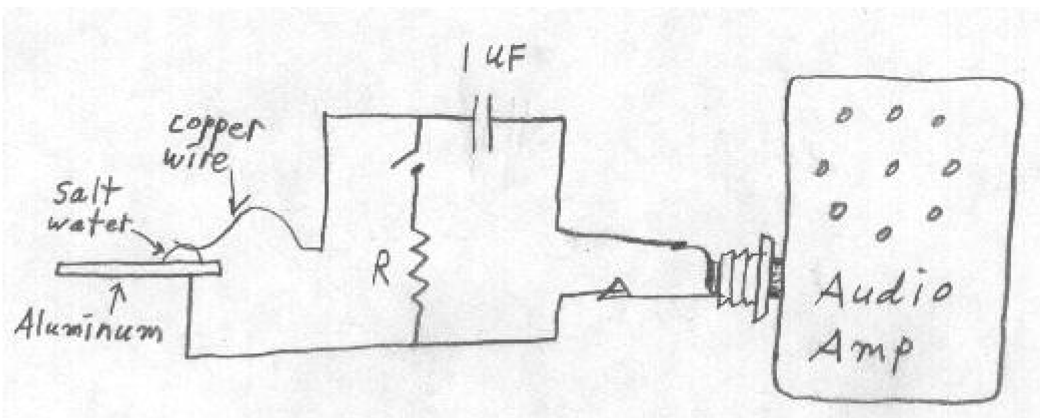
In addition, this device can actually produce a voltage by heating one of the oxidized wires. A volt-ohm meter set to the lowest dc current range will easily show the voltage generated. This can produce more voltage than any thermocouple that I have yet made. A meter set on the lowest dc current range also serves as a very low voltage meter.

Peculiar Sounds from Aluminum.

By Nyle Steiner K7NS 15 Sep 2003.

Peculiar Sounds from a Drop of Saltwater on Aluminum.





When the aluminum and contact wire above are connected to an audio amplifier, very strange and interesting sounds can be heard. This cell also produces a small voltage and there is generally more activity when R (100k to 1meg) is in the circuit drawing some current.

One of the materials tried with the drop of salt water, for photocell action was aluminum (see my article on the homemade photocell). No photocell action was observed with the salt water and aluminum cell but I did hear some very interesting sounds when it was connected to the audio amplifier. What makes these sounds interesting is that they are not just random noise as one might expect. The sounds contain many periodic pulse like tones that vary in pitch.

Recorded sound of salt water and aluminum cell. (400K .wav file):Recording of sound from the drop of salt water on aluminum.

Baking Soda Variable Electrolytic Capacitor.

By Nyle Steiner K7NS 18 Oct 2003.

Homemade Wide Range Variable Electrolytic Capacitor.

Variable capacitor is controling the frequency of a relaxation oscillator. With a circuit built around a 555 timer, it was easy to get a continuously variable range of 20hz to 100khz, a ratio of 5000 to 1. Typical capacitance range from the piece of aluminum in the above picture is from 10 uf to .002uf.

While experimenting with the borax rectifier, I found that everything also worked well using a baking soda solution (1 tablespoon baking soda to 2 cups of tap water). The aluminum strip shown in the above picture was cut from a piece of aluminum pie plate. I also discovered, with either the borax or baking soda rectifier, that it acted like a large capacitor as well as a rectifier when biased in the reverse direction. I had built a homemade electrolytic capacitor. I decided to do some experimenting and measurements to see what capacitance values could be obtained. I found it easy to get large values up to 100 uf. Since the capacitance is based on a thin film of aluminum oxide that forms on the aluminum plate, the capacitance can be varied by sliding the plate in or out of the baking soda sodasolution. By using a wedge shaped piece of aluminum, I was able to get continuously variable capacitance ranges of up to 5000 to 1.

This capacitor of course must be used, as with any electrolytic capacitor, with a positive DC bias on the aluminum plate. Although one would not expect great leakage specs from this capacitor, I found it to be quite useful in practical situations such as for controlling the frequency of a very wide range relaxation oscillator.

As far as I know, nothing like this has ever been available or even manufactured. most variable capacitors are the type used for tuning radios and they rarly have capacitance

values above 365 pf and their ratio of variation is not much better than ten to one. We are able to make here a variable capacitor with a capacitance variation range of 5000 to one and with max values of 10 uf or more.

The schematics below show different types of relaxation oscillators with their frequency determined by the value of the variable electrolytic capacitor. One is based on the 555 timer chip. Another is based on a UJT transistor. The choice of circuit is based merely on parts availibility although it is easier to obtain a wider frequency range with the 555. For those who are really adventurous, a zinc negative resistance relaxation oscillator can be built and is also shown (see Zinc Negative Resistance Oscillator).

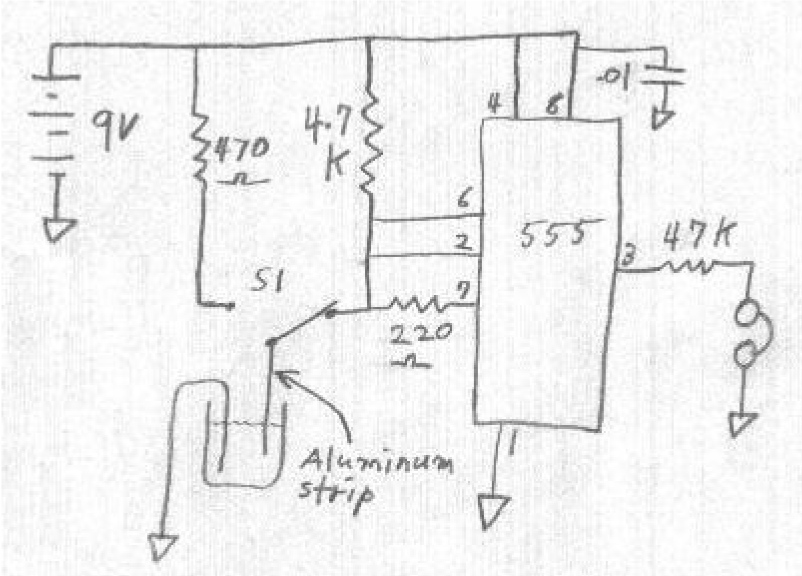
The capacitor is easily made by putting two electrodes into a solution of baking soda. One electrode must be aluminum but the other can be just about anything that conducts electricity such as lead, steel, stainless steel or even carbon. In the picture above, a piece of stainless steel sheet is used for the electrode opposite the aluminum. Both electrodes can be aluminum if you want to make a capacitor capable of working with ac voltages. The electrode opposite the aluminum is kept immersed into the solution while the aluminum electrode is moved in and out of the solution to vary the capacitance.

When the aluminum is first dipped into the solution, it causes a short to ground through the solution. To form the capacitor, the aluminum plate is connected to a positive supply (S1 in the case of the 555 circuit) through a 470 ohm resistor. The aluminum plate should at this time be dipped most of the way into the solution and swished around for about 20 seconds while a thin film of aluminum oxide forms on it. The aluminum plate becomes the positive side of the capacitor. The aluminum strip is then switched back to the oscillator circuit (using S1). S1 is omitted in the UJT and negative resistance circuits for clarity but the requirements for forming the capacitance are the same as with the 555 circuit.

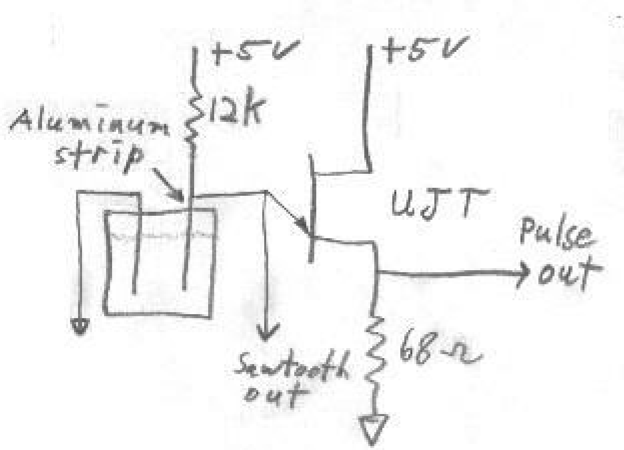
The oscillator is most likely to start running when the aluminum strip is dipped a very short distance into the liquid. The frequency may be out of hearing range and you may need a scope to determine if it is running. The frequency will get lower as the strip is dipped farther into the solution until the leakage becomes great enough to make the oscillator stop. As the aluminum strip is repeatedly dipped in and out, the capacitance and frequency range seem to improve until the strip can be dipped almost its entire length creating the greatest frequency variation range. With the 555 circuit, I was able to make continuous frequency sweeps from 10hz to 100khz.

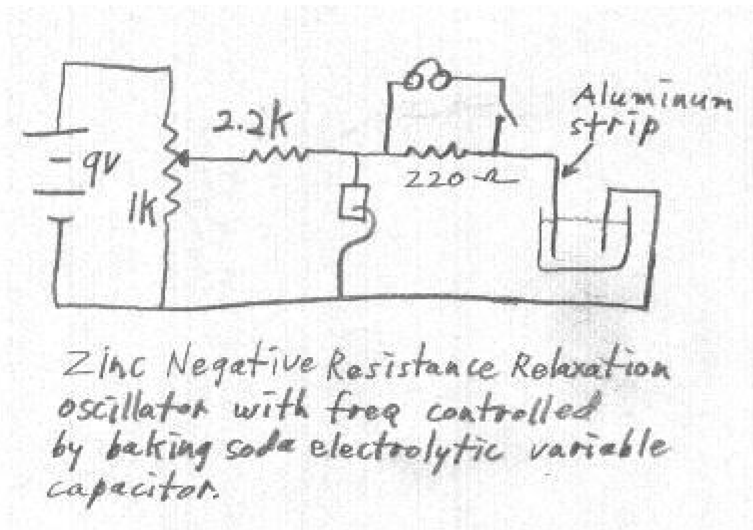
If the electrode opposite the aluminum is slid in or out of the solution, very little effect on frequency is noticed. This shows that the capacitance is happening at the aluminum electrode (strip).

Wide frequency range oscillators with homemade variable capacitor.



Baking Soda variable electrolytic capacitor used to control freq. of audio oscillator.



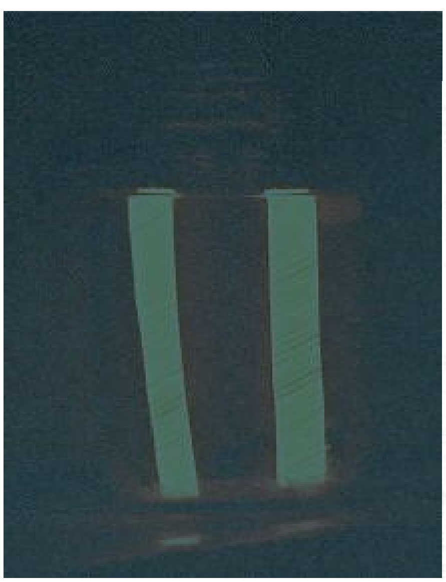


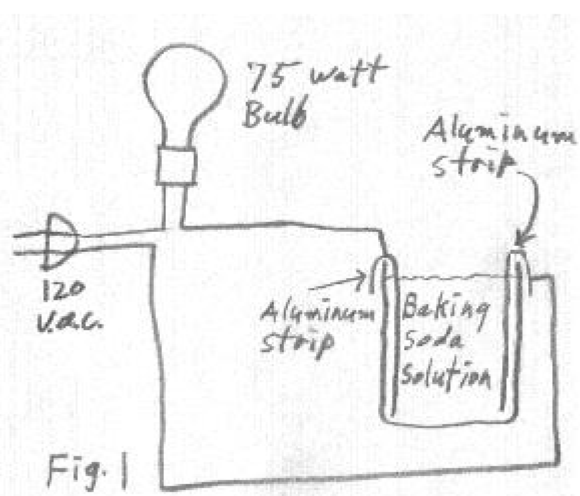
Three different relaxation oscillator circuits capable of very wide frequency variations when connected to the homemade variable electrolytic capacitor. For the really adventurous, a zinc negative resistance circuit is also shown.

Borax or Baking Soda Rectifier and the glow.

By Nyle Steiner K7NS 18 Oct 2003.

How To Observe The Glow From A Borax Or Baking Soda Rectifier.





Actual photo of the glow from two aluminum strips and the circuit for observing it. This setup is like two diodes back to back and draws very little current. The glow is produced on the reverse bias cycle of each rectifier. This is a circuit connected directly to the power mains. Use proper precautions.

In the early days of amateur radio, the dc plate voltage power supply for the transmitter, was often made using homemade rectifiers. From what I have read, these rectifiers would usually consist of an aluminum and lead electrode in a jar of Twenty Mule Team Borax solution. Borax is another name for sodium tetraborate. The aluminum becomes the cathode after a forming process of applying some ac current through the rectifier. Often, many jars were used in order to accomodate high voltages. It has been reported from various sources, that these rectifiers would also emit a faint glow when in operation.

While experimenting with these rectifiers, I have found them to work quite well and I have been able to observe the glow. It was also easy to make full wave rectifiers using more than one rectifier in traditional full wave rectifier circuits.

A rectifier can be easily made by mixing borax or baking soda into a pint jar of water and inserting an aluminum strip and a strip of another metal. After a forming process of running ac current between the two electrodes, the aluminum electrode becomes the cathode and the other electrode becomes the anode.

It seems that aluminum is necessary for the cathode, but the anode can be just about anything that conducts electricity. The aluminum cathode can be a 3/8" wide strip cut from an aluminum pie plate. The anode can be lead, carbon, steel or stainless steel. Copper tends to make a bluish green mess and does not seem as desireable. I have found most types of anode materials to work the same but the differences may be a long term effect not easily observed in the course of my experiments.

In all of my experimenting, I have found that baking soda works the same as borax. The solution can be made by either mixing 1 tablespoon of baking soda into a pint of water or by mixing Twenty Mule Team Borax into a pint of water until no more dissolves. Also, this is the first set of experiments that I have ever done with solutions conducting electricity, where the solution has not turned some yucky dark color. The solution seems to stay reasonably clear.

As mentioned earlier, there is a faint glow associated with these borax (or baking soda) rectifiers that can be observed in a dark room. It seems that moderately high voltages are necessary in order to produce the glow. The glow is produced on the aluminum plate when it is at the positive (reverse bias) part of the cycle and minimum current is flowing. For those who know what they are doing and are comfortable doing this kind of thing, the glow can be easily observed by connecting a 75 watt incandescent lamp in series with the rectifier and 120 vac line voltage. When first connected to the 120 vac, the lamp turns on at full brilliance. After a few minutes, the rectifier forms and the light intensity dies down to half brilliance. The lamp is now running on dc (half wave rectified). At this time the glow can be observed on the aluminum electrode if the room is sufficiently dark.

A 75 watt lamp running even at half brilliance makes it difficult to darken the room adequately. I find it easier to observe the glow by using aluminum strips for both electrodes in the jar. This creates a situation of having two rectifiers back to back, allowing very little

current to flow through the lamp. When connected to power for the first time, the 75 watt lamp lights up to full brilliance. The rectifying layer then start to form on the aluminum plates until after a few minutes, the lamp brilliance dies down to nothing. At this time, both aluminum strips will be glowing.

Where the electrodes contact the top surface of the liquid, tiny flashes can sometimes be observed in addition to the glow that covers the entire electrode. This condition seems to be more prevalent with the baking soda solution than with the borax solution.

You must do any experiments connected directly to the power mains, at your own risk. I don't recomend doing this experiment unless you are familiar with the hazards that exist. There are many who question the sanity of doing experiments that are connected directly to the power mains. Granted, this creates hazards, but if precautions and common sense are used, it is less hazrdous than driving to the grocery store or being a referee at your daughters soccer game. I believe it is totally acceptable for a conscientious person with common sense to conduct, with proper precautions, experiments that are connected directly to the power mains. I will offer some suggestions however, which I do not claim to be complete.

1. Treat all parts of the circuit as though they are a red hot heating element. Only touch when you are sure the circuit is disconnected (unplugged) from the power mains.

2. Never do these experiments with bare feet.

3. Keep all parts of the circuit far enough away from metallic objects to prevent inadvertent contact with them. Use a wood or formica table.

4. Do the experiments where you are not likely to touch any metallic objects or grounded metallic objects such as water faucets, sinks, telephones etc.

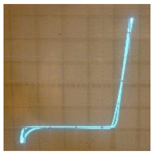
5. Avoid doing experiments in wet environments.

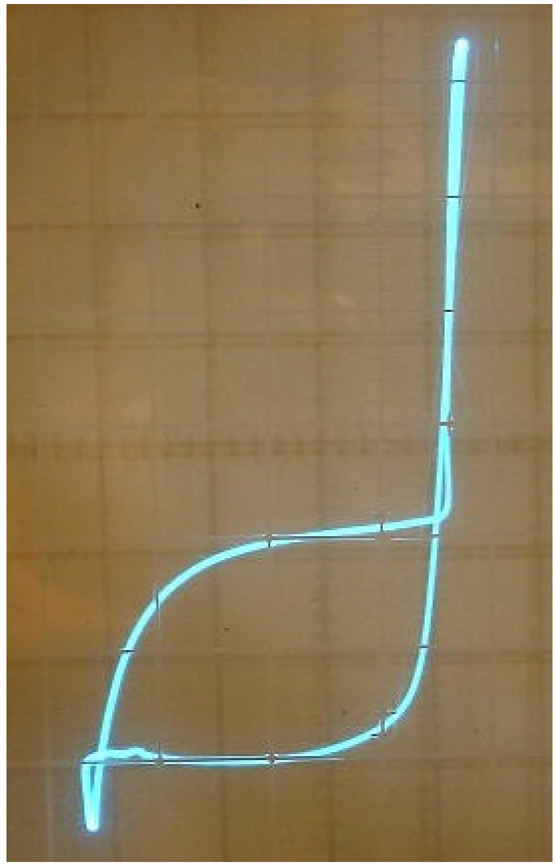
6. Never connect experiments to other equipment unless you really know what you are doing and can absolutely assure proper isolation.

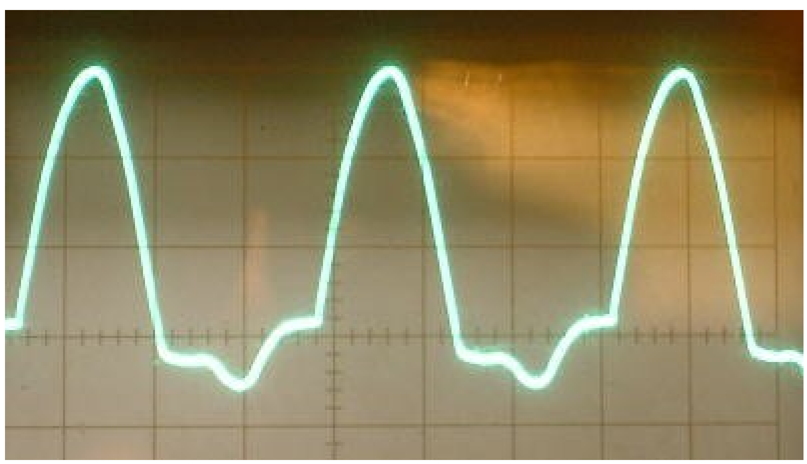
7. When making necessary adjustments to an operating circuit, always strive to do it with one hand and don't touch anything else while doing it.

8. Never leave exposed circuits that are connected to the power mains, unattended.

Characteristics of Rectifier.







The rectifier tends to also act like a capacitor. The first picture from curve tracer, shows rectifier curve with very little plate area immersed in solution and little capacitance. The second picture from curve tracer, shows rectifier with more plate area immersed producing a lot more parallel capacitance. The third picture from oscilloscope, shows waveform when one rectifier is used for half wave rectification. The reverse breakdown voltage tends to adjust itself to a point slightly below the peak value of the applied ac voltage. This can be seen by the

dip at the left of the curves and the small dip at the bottom of the half wave rectified waveform.

The oxide coating on the aluminum plate tends to form large capacitance values in parallel with the rectifier (up to many microfarads). The capacitance therefore can vary greatly, depending on how far the aluminum electrode is dipped into the solution and how long the rectifier has been forming. I have in fact, found it easy and practical to use one of these rectifier cells as a wide range variable electrolytic capacitor capable of controlling the frequency of an oscillator over a very wide range (see article on variable electrolytic capacitor).

Because of this large capacitance, there seems to be an optimum plate area associated with the aluminum plate. The curve trace on the second picture above shows a capacitance loop caused by the aluminum strip immersed well into the solution. The curve trace on the first picture is flat in the reverse direction because the aluminum strip was just slightly dipped into the solution.

This opens up another very fasciniting possibility. A cell with two adjustable aluminum plates (a variable capacitor) might very well be useable as an efficient light dimmer. With varying capacitance, no power is dissipated in the cell when creating a drop in voltage being applied to the lamp. I tried using a cell with two aluminum plates as a light dimmer. By lifting both aluminum plates out of the solution simultaneously, I could dim the 75 watt lamp to any desired brightness. The only problem is that as time goes on, the plates usually continue to form, and the overall maximum capacitance eventually drops to a value too low to supply adequate current to the lamp.

The forward voltage drop of these rectifiers seems to be about 5 volts.

The reverse breakdown voltage of these rectifiers tends to adjust itself to a point slightly below the peak of the applied voltage. When the ac voltage is increased, this breakdown value increases accordingly. When the ac voltage is decreased, this breakdown value decreases accordingly. This can be seen in the pictures above as downward dips in left portion of the curve from the curve tracer and at the bottom of the half wave rectified waveform.

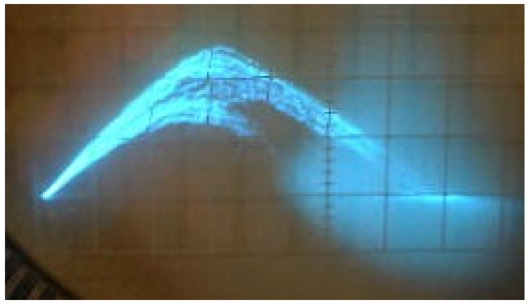
Negative Resistance.

I have observed an interesting N type negative resistance effect that happens only when the tip of a very sharp aluminum electrode is just barely touching the top surface of the solution. The curve trace is shown below.

There is a bright but tiny orange glow at the point of contact but I don't believe it is the same phenomena that causes the rectifier glow because in this case, the glow happens when the aluminum is biased negative. With the rectifier, the glow is generated when the aluminum is positively biased.

This generates a lot of rf noise as the large misty area at the right part of the curve suggests. Having done just a little experimenting, I have not yet heard a real clear tone generated from this device but I can hear noise in a nearby am receiver up to the receiver's limit of 30 mhz.

Borax Solution Negative Resistance.



An interesting N type negative resistance effect that happens only when the tip of a very sharp aluminum electrode is just barely touching the top surface of the solution. This generates a lot of rf noise as the large misty area at the right part of the curve suggests.

Simple Homemade Photocell.

By Nyle Steiner K7NS 12 Sep 2003.

Homemade Photocell and Setup for Experimentation.

An audio amplifier can be connected in parallel with the meter. This allows photocell action to be evaluated either by watching the meter or by listening to the amp. Light that is fluctuating at an audio rate and striking the photocell will be heard in the amp.

This is a copper oxide photocell and is very simple to make using materials found around the house, yet it seems to serve the purpose as well as similar but more complex homemade photocells that I have read about elsewhere. Although this photocell does not produce enough power to charge batteries or run circuits etc, it can be used for things such as a light sensor or as a pickup to hear a sound modulated light beam. Just imagine the thrill of hearing a sound modulated light beam through a homemade photocell.

To make this photocell, you simply heat a small area on piece of thin copper sheet, red hot in a propane flame, for a minute or so and let it cool. A photocell can now be formed by putting a drop of strong salt solution on the oxidized copper plate and bringing a piece of clean copper wire in contact with the drop. That is all there is to it. The copper wire can be held in place by attaching it to a small block of wood that sits near the copper plate. The plate is one terminal of the cell and the clean copper wire is the other. All pieces of copper that I tried, such as .006 copper sheet from the craft store or a piece of copper tube, worked well.

When this photocell is connected across a volt meter, a small voltage (a few millivolts) will be measured. The copper contact wire on the salt water drop becomes the negative terminal. This voltage can increase 5 to 20 millivolts by just shining a small flashlight on to the drop of salt water. By connecting this homemade photocell to an audio amplifier, audio and even music can be heard from a sound modulated light source.

I prefer the use of analog volt meters over digital ones for this kind of experimentation. The analog meter can give you a much faster feedback and better overall interpretation of what is happening. A digital meter can still serve the purpose well but getting a good feel for what is happening can be difficult when all you see is a bunch of changing numbers.

I have found that it is not necessary to remove the top layer of black oxide as is suggested in other articles. Sometimes these homemade photocells actually work best on the black oxide areas. One big advantage of this drop of salt water method, is that the whole copper plate does not have to be rigorously prepared. One small spot of good oxide on the copper plate is all that is necessary to make a good photocell. Most pieces however, have a large percentage of usable

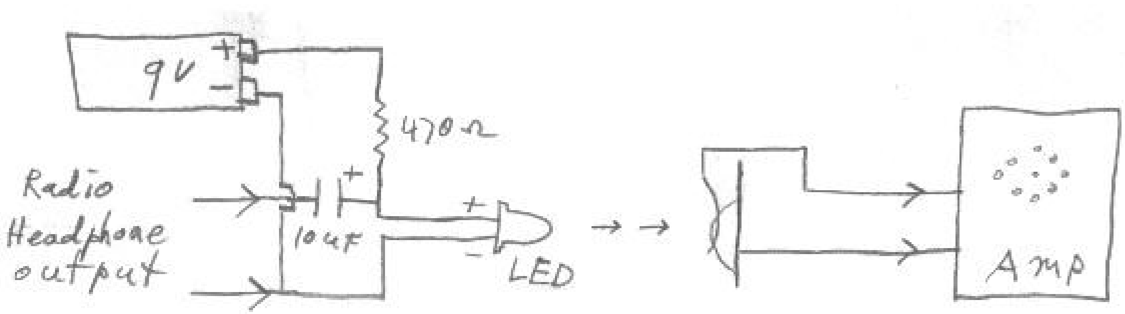
area. Numerous drops of salt water can be placed in various locations on the surface of the oxidized copper plate. The best spots can then be found by touching the copper wire to the different drops of salt water. All pieces of copper that I have heat treated work as a photocell but some are better than others. The challenging aspect is not in making the photocell work, but merely in getting optimum performance from it. One photocell that I made could give a whopping 50 mv increase when the light from a small flashlight was directed on to it.

I usually work under some fluorescent lights which vary in intensity 120 times a second (upper and lower halves of the 60 Hz power waveform). I can also connect the plate and copper wire to an audio amplifier and listen for 120 cycle hum in the amplifier as I touch the copper wire to the different drops of salt water. The best places are easily recognized by the loudest hum. The photocell action can then be verified by blocking the light and hearing the 120 cycle hum diminish or go away completely. The little amplifiers from Radio Shack that fit in the palm of your hand, work well with these homemade photocells.

Finding the best spots for photocell action.

While working under fluorescent lights or with a sound modulated LED near by, several drops of salt water can be placed on the oxidized copper sheet. By connecting the photocell to an audio amplifier, the best spots on the copper sheet can be found simply by touching the contact wire to the different drops of salt water. The copper sheet shown could be easily cut into several good photocells after the good spots are found.

Transmitting Sound On A Light Beam and Hearing It With The Homemade Photocell.



Top picture is a photocell being used as a pickup for sound modulated light from an LED. Distance can be greatly increased with lenses or by using a sound modulated laser pointer. The middle picture is a diagram of how to produce a sound modulated light using a LED (the very bright 2000 to 5000 mcd output ones work best). The headphone output from a small radio is a good source of audio to transmit on the light beam. The lower picture shows a photocell connected to the amp for hearing sound modulated light.

Other Light Sensitive Materials.

Since it is so simple to place a drop of salt water on any material, it is easy to explore different materials for photocell action. So far, I have found Iron Pyrites and Galena to exhibit a lesser but noticeable amount of light sensitivity. I also used a steel contact wire to contact the salt water drop on the Pyrites and Galena to make sure that the signal I was hearing, was not just the result of light sensitivity of the copper contact wire itself.

Silicon is Really Hot Stuff.

I made some really hot photocells that put out a much louder signal from the sound modulated light, using scrap pieces of silicon. These pieces are some sort of scrap from the semiconductor industry and are available at almost any rock shop or rock show. The only drawback with the silicon is that it is not as fun as using a more common household material such as copper to make a photocell. A metal clamp was placed around the piece of silicon to make contact with it. A drop of salt water was placed on the silicon and a piece of wire was then brought into contact with the drop just as described above.

Photocell Made From A Piece Of Silicon.

The rough looking pieces of silicon worked best. The smooth polished like silicon pieces didn't work as well unless they were broken in two. After breaking a piece in two, the newly exposed faces would usually make a very good photocell. Almost all of the silicon pieces that I had around worked very well.

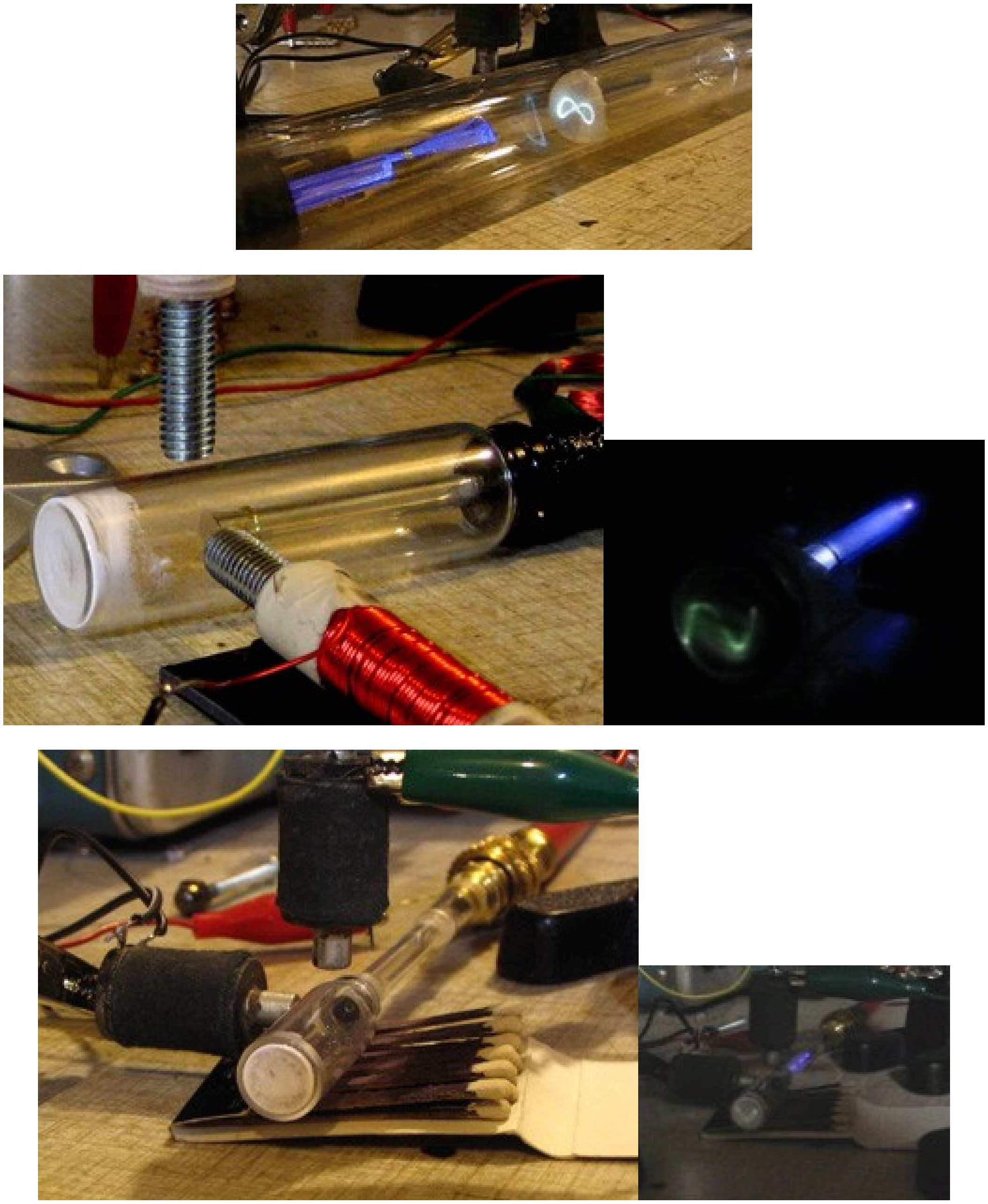
The silicon photocell was very peculiar in that I was not able to observe any dc voltage or current from it even though it produced a very much stronger audio signal from the sound modulated light. It acted similar to a normal photocell, that produces dc, but in series with a capacitor. When a flashlight beam is first directed on to the silicon photocell, a positive voltage will rise and then settle to zero while the beam is held in place. When the flashlight beam is later removed, the voltage (that now has settled back to zero) from the silicon cell will drop to a negative value and settle back up to zero.

Selenium Rectifier is also hot for photocells.

Using the same drop of salt water method, a plate taken from an old selenium rectifier also worked very well as a photocell pickup for sound modulated light. Unlike the silicon cell, casual observation showed that the selenium photocell, like the copper oxide cell, could produce a steady dc voltage from a steady light source.

Homemade Cathode Ray Tubes.

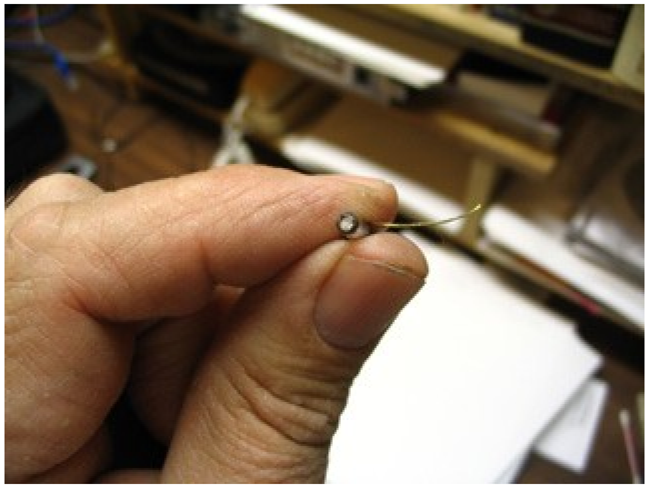
By Nyle Steiner K7NS Oct 2007.

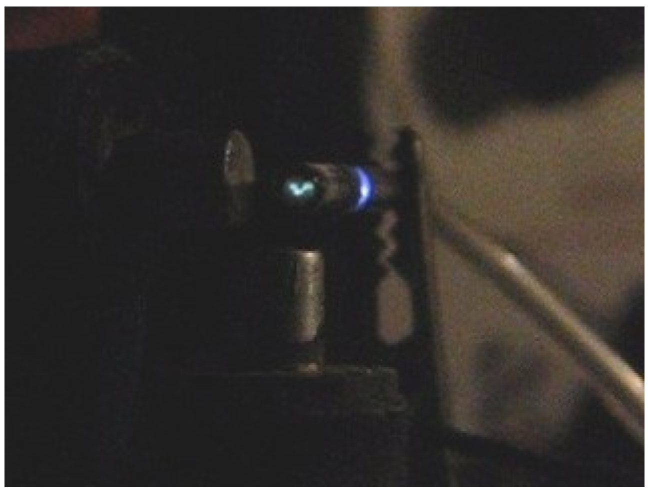


Several Homemade Cathode Ray Tubes.

This picture does not include the tiny 3mm diacrt.

3mm Outside Diameter CRT.





This very tiny CRT pictured above, was made using 3mm outside dia. glass tubing. It's face can fit loosely inside a 1/8" hole. The cathode (visible on the far end) is made of 1/16" dia. aluminum tubing. It also serves as the evacuation tube.

Cathode Ray Tube Details.

The cathode ray tubes that I am describing here are crude and they are relatively easy to make at home. They are in fact, much easier to build than most technically minded people would ever imagine.

My reasons for building these homemade crt's should be obvious; certainly not to save money in building a TV set, but mostly because they emit a very intense fun field. Building these crt's fulfills one of the passions I aquired very

early in life from looking into the back of a TV set many times, and watching the glow of the vacuum tube filaments and the wonderous light from the crt.

In order to be satisfied that I had really made a working cathode ray tube, I had to build device that could direct an electron beam toward a phosphor screen, and be able to at least display Lissajous figures by deflecting the beam with magnetic coils. All of these crt's did that to my great satisfaction.

These cathode ray tubes are of the cold cathode type. That is, the cathode is merely an electrode without a heater or filament. They are simply a modified discharge tube operating with ionized air at an easily attainable degree of vacuum, even several hundred microns. I do not feel that my observations of pressure are incredibly accurate but I believe I was getting the tiny 3mm diacrt to operate at pressures in excessa of 1 torr. As a general rule, the bigger the crt, the lower the vacuum pressure needs to be. I believe the large crt using the bottom of a vial inside a large glass tube, was operating at around 100 to 300 microns.

The HV power supply for these crt's was improvised using the output of a Variac into the primary of a neon sign transformer. The secondary was rectified using a high voltage diode that I found on ebay. The filter was three microwave capacitors in series. Each capacitor had its own 10 megohm shunt resistor to keep the voltage distribution across the capacitors uniform. It may also be possible to improvise a high voltage rectifier by putting several 1N4007 diodes in series. Each diode should also be shunted with a 10 megohm resistor to keep the voltage distribution across them uniform. Without these resistors, there is a tendacy for the

lowest voltage tolerant device to fail first, putting even more voltage across the remaining devices. Each time a divice fails the remaining ones receive more and more voltage until they all fail.

With this power supply, it is easy to adjust the voltage between zero and about 5 kv. These crt's seemed to operate well in the voltage range of about 2 to 5 kv.

All crt's used a 1 megohm resistor in series between the cathode and the negative end of the power supply. I made a 12.5 watt 1 megohm resistor using 25 1/2 watt 1 megohm resistors soldered together in a series-parallel configuration.

When doing this kind of work, there is always the concern about x-rays. I can not assure anyone that these cathode ray tube experiments are free of x-ray hazards. I will say however, that I have read somewhere that there is not much danger of x-rays until you start using voltages above 15 kv. In all of my experiments here, I have been using between 2 and 5 kv.

I do not have the facility to make high quality sealed vacuum devices and therefore, thesecrt't are operated while the vacuum pump is running. I control the vacuum pressure by opening and closing a stopcock in the vacuum line. I used a standard mechanical pump as used by refrigeration servicemen and standard 1/4" flare fitting hoses. These hoses are far from what any vacuum expert would consider adequate for this kind of work.

I believe that if one were desperate and dedicated enough, one of these smallest crt's could be made to work using my simple homemade hand pump as described in the August 1966 Amateur Scientist column of Scientific american. I intend to try it soon.

Cathode Ray Tube Misconception and the Morris & Lee Quote.

There is a big misconception that says cathode ray tubes can not operate at pressures as high as these are operating because of a prohibitively short molecular mean free path. Even many highly educated physicists will tell you that a crtcan not operate at these pressures. What many do not realize however, is that while the molecular (air molecules) mean free path is very short, the mean free path of electrons in the same environment is many many times longer.

I would like to put here what I call the Morris & Lee quote, an excerpt from a pamphlet I bought from them in the late 1960's. The pamphlet describes many interesting high vacuum experiments.

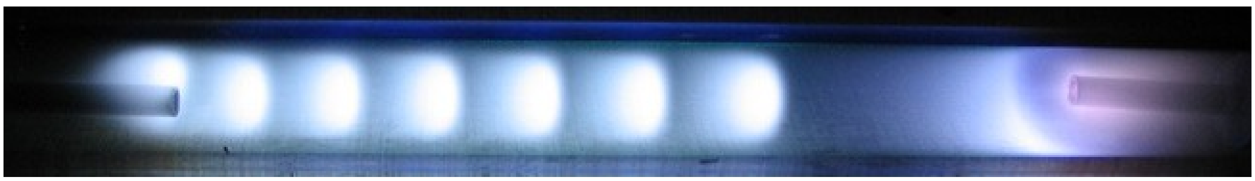
"The distance a molecular or atomic particle can travel is directly dependent upon the space between the stray molecules in its surroundings. For example, air molecules at atmospheric pressure can travel on the average only a few millionths of an inch before they are deflected by collision, with another molecule. At aa pressure of 1 mm Hg an air molecule can go about .002" before collision and the much smaller electrons a distance of about 3/8". At a pressure of 1 micron, these distances increase to 2" and 30 feet respectively".

Because of this, these crt's work very well at vacuum levels easily attainable by amateurs. That pamphlet was part of my inspiration to build these crt's.

Imagine a very dense asteroid field like we see in many sci-fi movies. It is easy to see that a large fast moving asteroid would most likely collide with other asteroids before traveling very far. In all these scenes however, you can

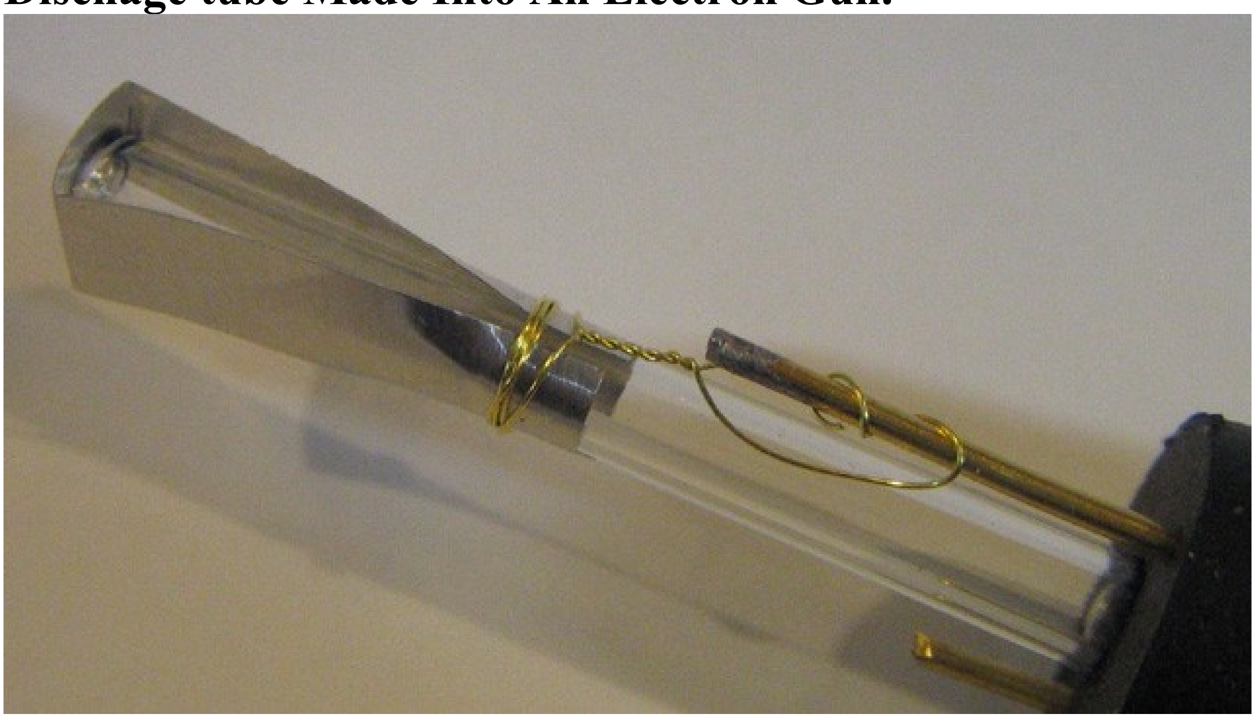
always see dark space in the background. It is easy to visualise the possibility of shooting a tiny but fast bullet between the asteroids into space without hitting any of them. It would appear that many paths are available where a tiny fast object could escape the asteroid field in a straight line without hitting any of the asteroids.

Standard Discharge Tube.



The standard discharge tube is the basic element of making a cold cathode CRT. This discharge tube is roughly one inch dia. The negative cathode is at the right end and the positive anode is at the left end. A well filtered DC of several KV will produce very distinct striations and discharge characteristics.

Dischage tube Made Into An Electron Gun.



Construction Details.

There are very few critical parameters when constructing these cathode ray tubes. The spacing between the electron gun anode and cathode was typically 1 to 2-1/2 inches in my experiments. The distance between the electron gun and the phosphor screen can vary greatly. Just keep in mind that a shorter distance will tend to make a crt with a brighter image and ability to work well at somewhat higher pressures. Notice in the picture of assorted crt's that one crt was built from a 1" diameter glass tube. The screen was a glass vial, that fit loosely inside the tube. It's outside bottom was painted with phosphor. The bottom (screen) of this vial faced toward the electron gun and the image on the screen was best viewed from the same side as the electron gun. The distance between the screen and the electron gun could be easily varied merely by tipping the whole crt and sliding the vial from one position to another.

The electron gun is nothing more than a small diameter discharge tube that has a small aperture in the positive anode. Electrons traveling toward the positive anode are moving fast enough that they travel right through the small aperture forming an electron beam. If the evacuated space extends beyond this aperture, you have a cathode ray tube. Thats it!!! Electrons traveling through the aperture into the evacuated space beyond strike whatever is in their path whether it be the wall of the vessel, some phosphor, piece of paper, metal or whatever. The electrons always seem to find their way back to the positive anode that they left behind.

This beam of electrons can be easily deflected with a magnetic field from either a nearby magnet or a current carrying coil. I did manage to produce a deflection with an

electrostatic plate but things are different in this respect from the commercialy made crt's, when the plate is in an ionized gas. More on this later.

I made most of my electron guns from 5 or 6mm outside diameter standard wall glass tubing. The positive anode (in the picture above) can be a strip of thick aluminum foil (cut from an aluminum pie plate) with a small hole punched in it. After folding the foil around the end of the small glass tube, the hole can be punched with a pin where it covers the end of the tube. The anode can also be a very small diameter metal tube. I also made an electron gun by simply constricting the positive end of the glass tube and placing the positive anode elsewhere in the crt.

The cathode (not visible) can be a 1/8" dia. aluminum welding rod sealed (any way you find handy) in the opposite end to the right. Note: It is best to use aluminum for the cathode in order to minimize sputtering, a process where metal atoms fly away from the cathode and coat the inner wall of the glass tube. This shortens the life of the crt. Aluminum has a very low sputtering rate as compared to other metals such as copper or silver.

Electrical connection terminals through a rubber stopper can be made using 1/16" dia. or smaller, welding rod or music wire. Just put a piece in a drill and, being careful not to also penetrate your fingers, drill it through the rubber stopper.

This assembly using the rubber stopper (just visible in the picture), can be stuck into one end of a much larger (1" dia.) glass tube or the mouth of a glass vial. The diagram below shows how to make a glass vial into a crt. Before inserting the electron gun into the mouth of the vial, I took a little

phosphor powder (from the broken fluorescent light), mixed it with some water and swished it around inide the bottom of the vial until it dried.

Every crt has an optimum vacuum level at which it operates best. The optimum vacuum level is always the highest level of vacuum (lowest pressure) that can be achieved before the discharge in the electron gun ceases. With every discharge tube, the discharge will cease when the pressure gets to a low enough level. A smaller diameter discharge tube will cease operating at a higher pressure level than a larger diameter discharge tube. Therefore, a crt with a smaller diameter electron gun must operate at a higher pressure than one with a larger diameter electron gun. A crt with the smaller diameter electron gun would thus typically end up being a smaller crt because of a higher operating pressure and shorter travel distance for the electron beam.

There are many materials that will produce a glow where they are struck by the electron beam. If the room is darkened, a blue spot can be seen where the beam hits the walls of the glass vessel.

For the face of most of my crt's, I used some phosphor powder salvaged from a broken fluorescent light that fell on the floor several years earlier. After some very choice words, I realized the opportunity to acquire some phosphor that I had always wanted to experiment with. The phosphor is a fine white powder that can be easily scraped from broken pieces of fluorescent light glass. It takes only a very tiny amount of this phosphor to make a cathode ray tube. This powder of course is one of the best materials to use for a crt face as it is designed for this very purpose, to fluoresce when bombarded with electrons. I simply mixed some of this

powder with water and applied it to the inside face of the crt and let it dry.

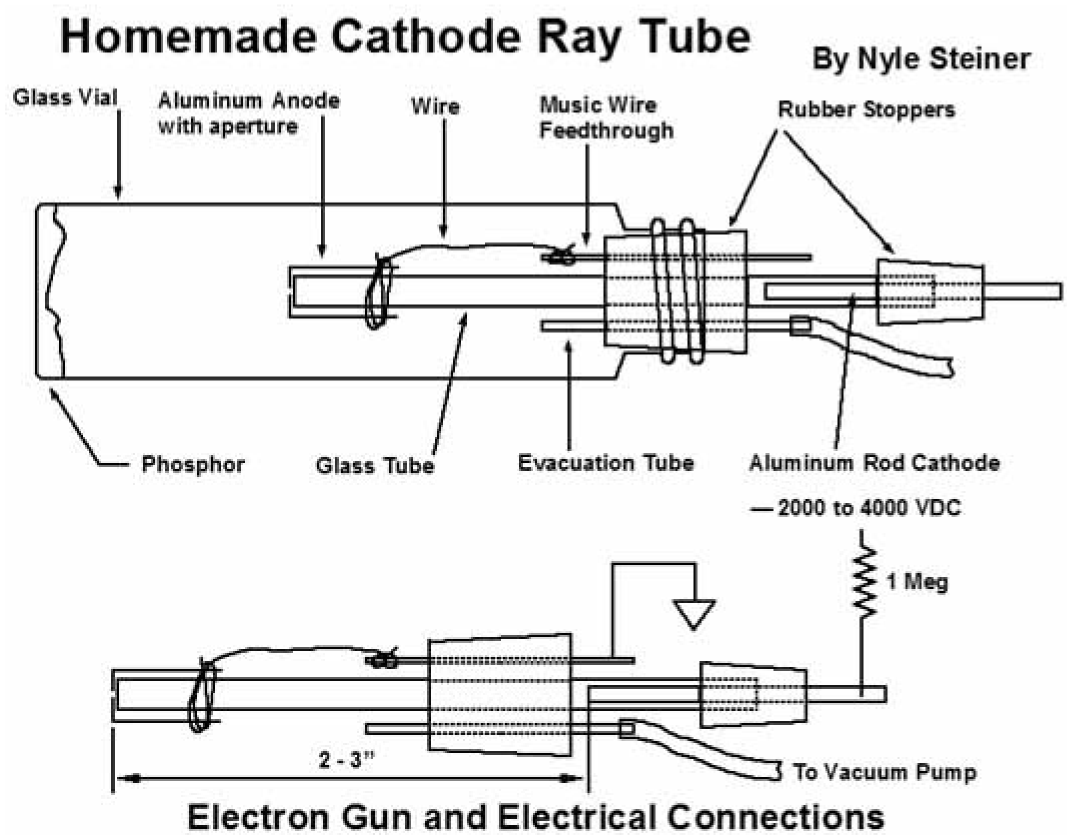
YEA YEA YEA!!! I am already aware of most of the toxic hazards of fluorescent lights but feel however, that these hazards are less severe than most of the hazards we face daily in our lives. I should say though, that anyone taking phosphor from a fluorescent light do so at their own risk. I have my opinions but I am certainly not an expert to give advice about the toxic hazards of fluorescent lights. I will say that since an early age, I have heard many times, never to get a cut or scratch from a piece of a broken fluorescent light.

I also found that a piece of paper painted with a highlight pen made a usable screen if the lights were very low. This could be an advantage if you are trying to impress your girlfriend. This screen as one might expect, worked best when viewed from the same side as the electron gun. This paper screen however, soon aquired a brown burn like spot where the beam would hit most of the time. I would suggest trying a flat piece of ceramic material painted with highlight pen to make a screen. That might work well as a rear view screen but I didn't try it for lack of a flat piece of ceramic.

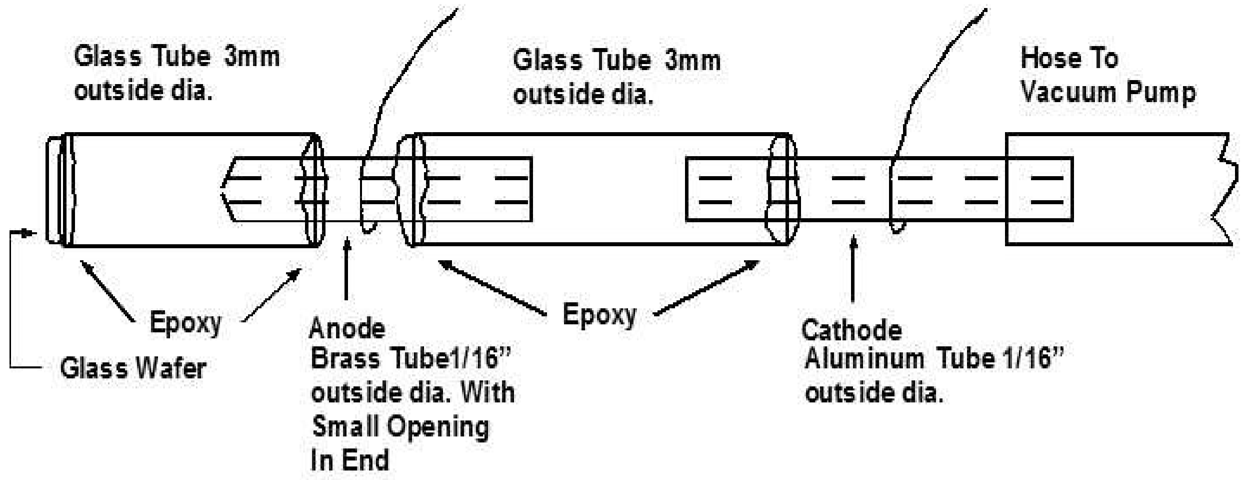
Clorox laundry bleach powder will fluoresce in the electron beam. I havn't tried doing this but, if this powder were to be ground very fine and mixed with water into a paste, it might make a usable screen phosphor. The highlight pen and bleach powder do not seem to fluoresce as well in the electron beam however, as they do under the influence of ultraviolet light.

Diagrams.

The drawing below shows typical construction for a crt using a standard glass vial. Almost any size can be used. A second drawing shows the construction of a tiny crt with an outside diameter of just 3mm.



Homemade Cathode Ray Tube 3mm Outside Diameter



With the 3mm crt, the spacings, between the anode and screen and between the cathode and anode, are somewhere between 1/8" and 3/16".

The screen was made by heating a glass tube in a flame and pulling it to a fine thread. After breaking the thread in two, it was fed into the flame to form a small sphere. The sphere was then taken out of the flame and pressed into a wafer shape between two microscope slides before it cooled. I had to try this about four times to get one that did not break after cooling and breaking off the remaining thread. This wafer was then epoxied on to the end of the 3mm diameter glass tube.

A tiny amount of phosphor powder can be dropped into the front end before epoxying the anode in place. Shaking the crt around with the face down will apply the phosphor to the screen.

The electron gun anode was a piece of 1/16" o.d. brass tubing about 3/8" long. The end facing the screen was made

into a tiny opening. This was done by putting the piece of tube in a hand drill and spinning the end against a piece of steel.

Firing Up The CRT.

When running these crt's they typically act as follows. The high voltage is turned on and the vacuum pump is started. Very quickly, the electron gun (discharge tube) starts to glow. As the pressure gets lower, striations form in the electron gun. As the pressure gets lower, the striations get larger and fewer and they will be near the positive anode. At the point of almost having no striations, a faint but fuzzy glow will start to be noticeable on the crt screen. The pressure is now getting just low enough that some of the electrons coming through the anode can make it to the screen. As the pressure gets still lower, the spot on the screen will become clearer and much brighter. The crt is now operating at the optimum vacuum (pressure) level. I always keep it at this point by turning a stop cock, between the crt and the pump, on and off. When the pressure gets still lower, the glow discharge in the electron gun will cease entirely and everything including the screen goes dark. Closing the stopcock will allow the pressure to start rising again and the spot on the screen and the electron gun will light up again.

It is easy to notice light from the electron gun hitting the screen and interpret that as the electron beam spot. You can verify that the spot on the crt face is the real deal by putting a magnet near the crt. You should be able to move the spot around very easily with a magnet.

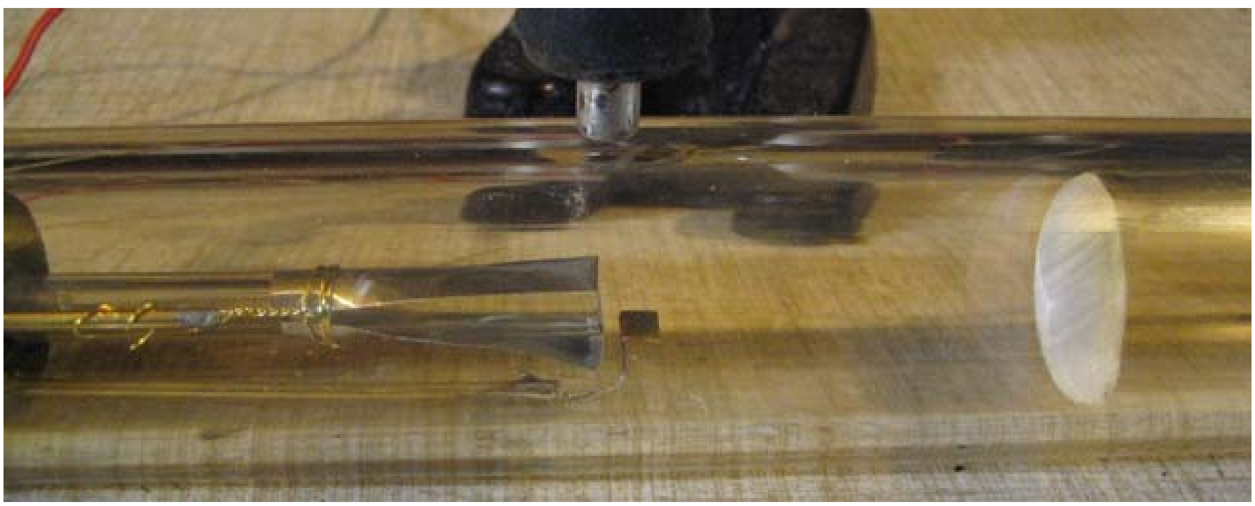
You can put coils near the crt to deflect the beam electronically. Placing a permanent magnet at the right

distance from the crt and in the right position, can act as a centering control.

Electrostatic Deflection.

Even though these simple crt's lend themselves to the use of magnetic deflection, I succeeded in producing vertical deflection using an electrostatic deflection plate. I did not put a lot of effort into this so It would not be surprising to hear of someone getting different results than what I will describe here.

Electrostatic vertical deflection plate and magnetic horizontal deflection coil.



The vertical deflection plate on the bottom and the horizontal deflection coil on the top appear to be opposing each other. This is the way it should be however because the electrostatic plate deflects the beam directly away while the magnetic coil deflects the beam at a right angle.

In all of my crt experiments I connected the electron gun positive anode to ground and the electron gun negative cathode through a 1 megohm resistor, to a negative dc voltage of several kv. All voltages applied to the deflection

plate were relative to the ground potential of the positive anode.

I drove this plate with the sound of an analog synthesizer using an audio amplifier output to a step up transformer. A negative bias voltage of 200 to 300 volts was applied in series with the output of the step up transformer so that the audio could deflect the beam through both negative and positive excursions. Using a 60 hz driven horizontal coil, the audio could be viewed much like you would see it using an oscilloscope. You can view a video of this experiment at youtube.com. Just search for Homemade Cathode Ray Tube and Oscilloscope.

An electrostatic deflection plate behaves somewhat differently in an ionized gas than it does in an ultrahigh vacuum as is used in commercially made crt's. The ionized gas tends to act as a conductive shield against the effects of an electrostatic field from a grid or plate. I found this out when experimenting with homemade vacuum tubes. Whenever the inside residual gas was ionized, the grid had no effect on electron flow between the cathode and plate.

In a commercially made crt, an electrostatic deflection plate will push the electron beam away from it when a negative voltage is applied and pull the electron beam toward it when a positive voltage is applied.

In the case of these cold cathode crt's however, I observed that with a negative voltage applied to the plate, the beam was deflected away from it as expected. With a positive voltage applied however, no deflection was observed. Instead, the applied positive voltage to the plate had a tendacy to sharpen the focus of the beam. The positively charged plate did not have to be anywhere near the electron

beam in order to tighten the focus. The positively charged plate could be almost anywhere in the crt.

Whenever a negative or a positive voltage was applied to the deflection plate, a small current would flow between the plate and the anode.

At first glance the picture above may look peculiar. The vertical deflection plate on the bottom and the horizontal deflection coil on the top appear to be opposing each other. This is the way it should be however because the electrostatic plate deflects the beam directly away while the magnetic coil deflects the beam at a right angle.

I had little success with the use of both vertical and horizontal deflection plates. That is why I used a horizontal deflection coil and a vertical deflection plate in this experiment. I believe that I once read somewhere online that Braun the inventor of the cathode ray tube, had similar results when trying to use electrostatic deflection with his cold cathode crt's.

SEMICONDUCTOR ARCHAEOLOGY.

or

TRIBUTE TO UNKNOWN PRECURSORS.

****

In the beginning of the era of radio, listeners received transmissions on a crystal set. This set consisted of an aerial, a tuned circuit, a detector and a earphone. (Figure 1.)

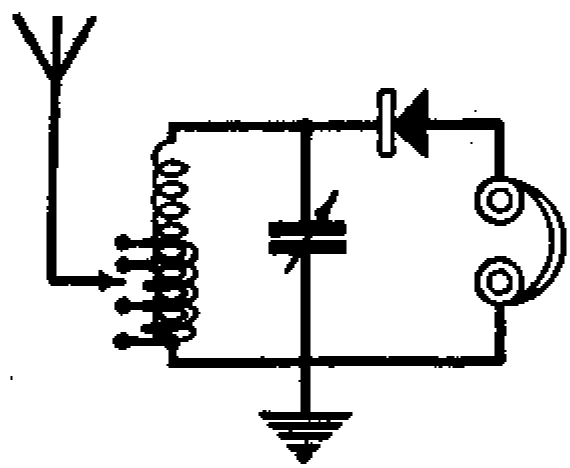


Fig 1. A classical crystal set..

The detector consisted of aanisotrope crystal of galena (lead sulphide), locked in a small cup. One or several flexible metalic wires (cat whiskers) made contact on the cristal. These wires where made of gold, brass, copper or steel ...This detector allowed an electric current to flow better in one way while jamming it in the other. One spoke of "unilateral conductivity". This allowed the rectification of a high frequency signal and the extracting of an audible or musical message.

The discovery of this rectifying property in certan crystals is credited to F. BRAUN in 1874.

This was put into application by **Greenleaf Whittier Pickard** (1877 - 1956) (See link below)

In 1938 one was still not able to ascertain the manner in which this happened. There was a great lack of knowledge in molecular physics and in solid material chemistry. It was thought that some sort of thermo action took place or that it was also electrical. In the years 1920-1922, a lot of home research about this function went on in Russia and the U.S.A. But the evolution of radio electronics was to be swamped by the mighty and rapid progress made with vacuum tube valves.This revolution made nearly every one forget the results and knowledge of the early days.

It was only in 1945, that real research started up again resulting in the production of something that was going to turn into today's semiconductors. Among these :
The invention of the point transistor by Bardeen, Brattain and Shockley. (Nobel prize in 1956)
The dicovery of the tunnel effect par Esaki.(Nobel Prize in 1973)

As to try and not totally forget all the work done on semiconductors before this recent period, we have tempted to list the description of materials used and the accomplishments made between 1920-1938. (This description has not got the pretention of being exhaustive.)

DETECTORS:
Three kinds :

- Contact between a crystal and a conductive pin.
- Contact (or junction) between two identical crystals.
- Contact (ou junction) between two non identical crystals.

Many crystals where tested:

- Bornite
- Carborundum (combination Carbone-Silicium)
- Cassiterite
- Cerusite
- Chalcopyrites
- Galena
- Ghane
- Graphite
- Hessite
- Hasmatite
- Hertzite
- Malachite
- Molybdemnite
- Pyrites
- Silicium
- Bismuth sulphide
- Tellurium
- Ulmanite
- Zincite ...

The most popular combinations where :

Contacts :

- Galena - Copper(Brass, Silver)
- Molybdenite - Silver ribon
- Iron Pyrite - Gold
- Carborumdum - Steel
- Copper - Silicium
- Zincite - Steel

And the junction :

- Chalcopyrite- Zincite (known as Perikon)

These devices made up, what are called today as DIODES.

The electrical and mecanical performances of these diodes depended upon the pressure of the contact (or junction) and of an eventual polarization

voltage.

Examples of prehistorical characteristic curves are shown in Figure 2.

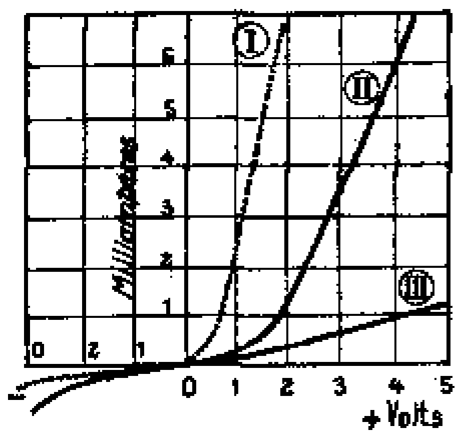


Fig 2.
I Contact Perikon (Zincite-Chalcopyrite)
II Contact Carborundum-Steel
III Contact Zincite-Steel

Zincite was made by using natural Zinc oxyde (ZnO) and heating it with an electrical arc in the presence of manganese peroxyde or manganese bioxyde. In our opinion, the most interesting device was made up by the contact between Zincite and Steel. (sometimes Carbon) But the ancient characteristic curve in Figure 2 does not show it's most exciting aspect.

In **1923**, Oleg Losev (1903-1942) (See link below) managed to make a high frequency generator using such a detector. But it was polarized. This indicates that this diode had a characteristic curve in which a ***negative slope was present***. And this makes one think of the tunnel effect diode invented a half a century later.

In Figure 3, we have the characteristic curves of a normal diode and a tunnel diode where this negative slope is visible.

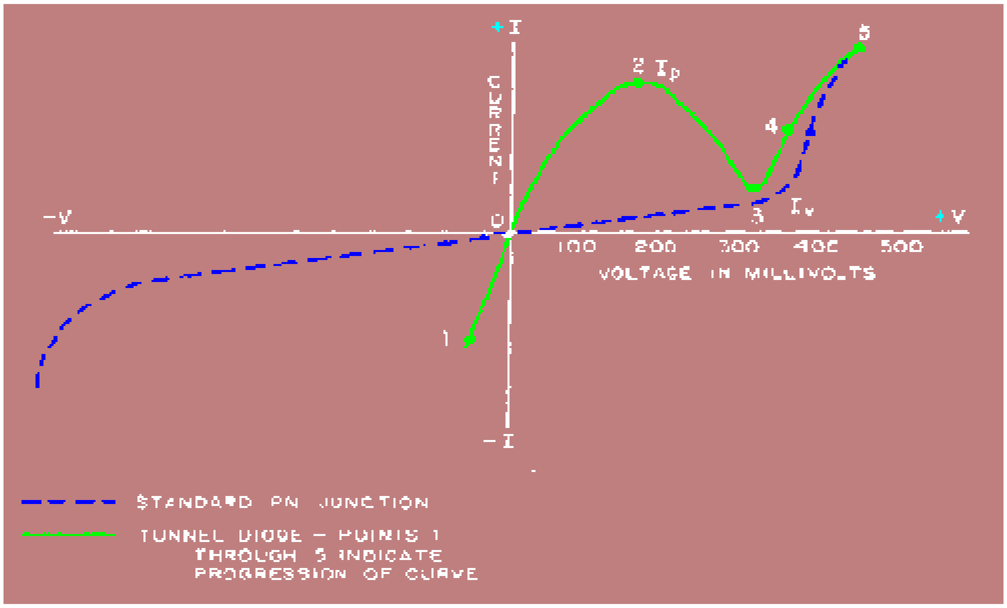


Fig 3.
Tunnel Diode
The green curve has a negative slope between 200 and 300 mV.

Unknown precursors then took advantage of this discovery to build, way before out time, some semiconductor devices. That is to say :

- heterodynes
- regenerative receivers
- low frequency modulators
- autodynes
- low frequency amplifiers
- high frequency generators(8 to 12 Mhz)
- transceivers...

These layouts were part of what one called **CRYSTADYNE** systems. (Sometimes called CRYSTODYNE)

But in those days, the technical performance and industrial ease of the new increasing valve technology made these layouts to be ignored, and then forgotten.

Here in the Figures 4 to 7 we show four original schematics of the

"Cristadyne" technology.
They were printed before 1938.

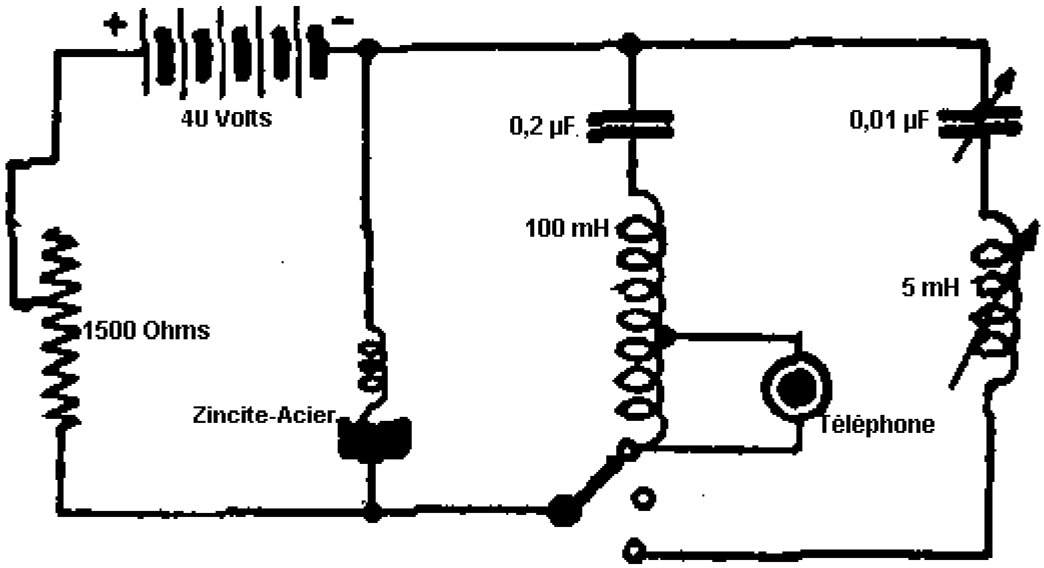


Fig 4.
Zincite Heterodyne

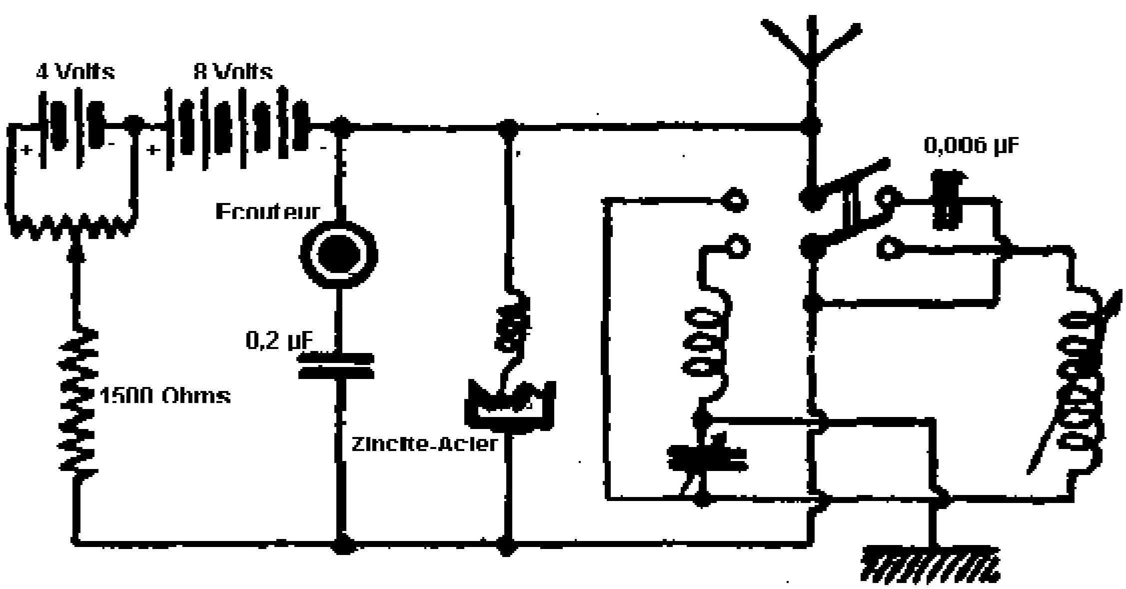


Fig 5.

Crystadyne receiver.

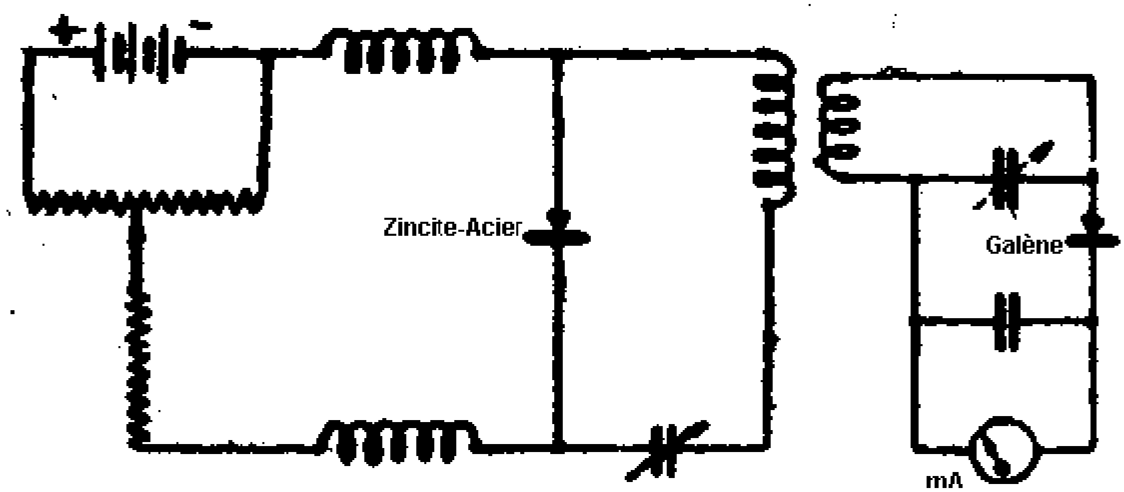


Fig 6.
Zincite heterodyne for short waves.

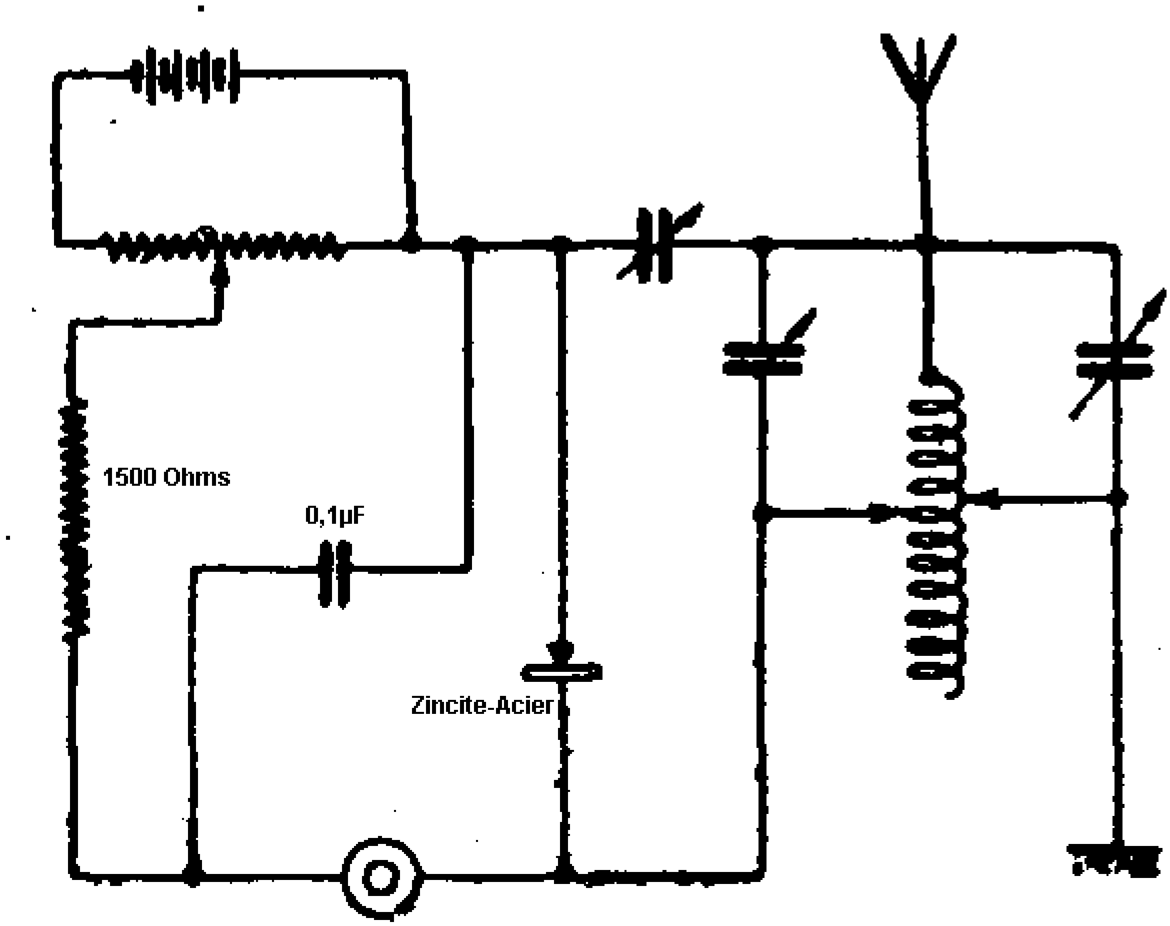


Fig 7.
Zincite modulator. - Low frequency "tikker".

Negative resistance oscillators

Considering the amount of attention given to *superconducting* materials which have an effective electrical resistance of zero it is surprising that the property usually called *Negative Resistance* is so little known. Yet devices and systems exploiting this effect are widely used to make amplifiers and oscillators in the microwave, mm-wave and Terahertz frequency range which lies between conventional electronics and infra-red optics. Many materials and devices exhibit negative resistance — *IMPATT* diodes, Multiple Quantum Well's, etc. Here we will use the example of the *Gunn*effect, named after its discoverer. Figure illustrates the *I/V Curve* of a suitable piece of semiconductor material. This shows how the current through the material varies with the voltage applied across it. Various sorts of semiconductor show this effect, but the types used most often for commercial purposes are GaAs and InP.

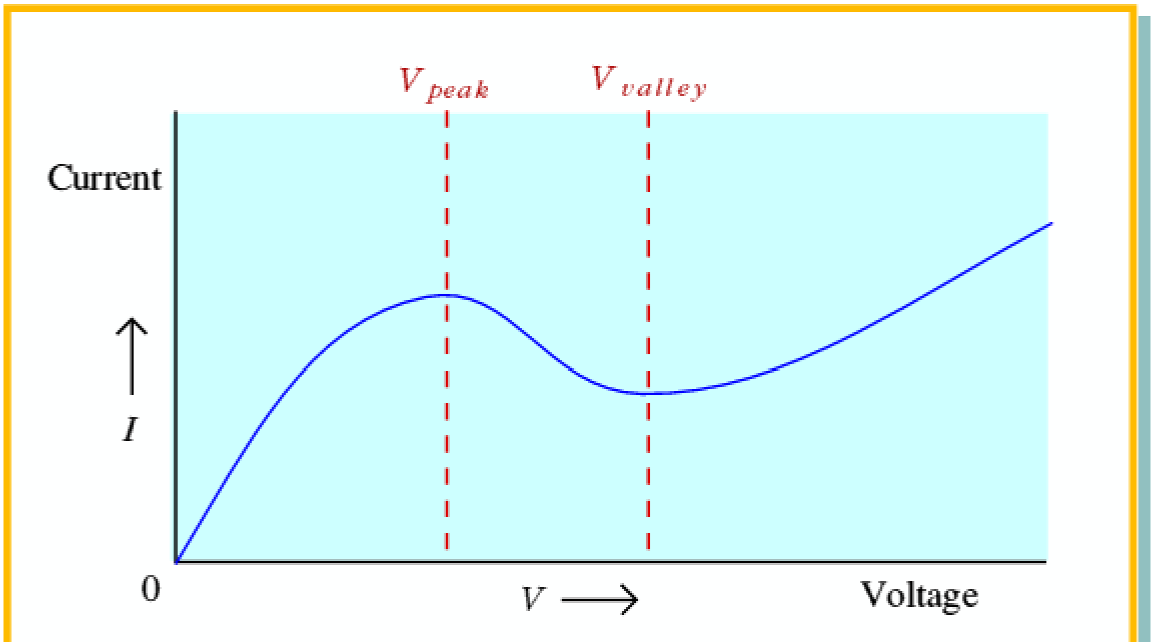


Figure 5.1 I/V curve of a Gunn diode.

A *Gunn Diode* is essentially just a piece of doped semiconductor with two electrical contacts on opposite ends. (In reality, most Gunn Diodes are more complex than this to make them work better, but these details don't matter here.) Its called a “diode” because it has just two wires and has a *non-linear* I/V behaviour like normal diodes. However, unlike ‘real’ diodes its I/V behaviour is symmetric — i.e. if a voltage, V, gives a current, I, then a voltage, $-V$, will give a current, $-I$.

There are two ways to define the resistance of a device or piece of material. In most circumstances we use the *Static Resistance*,

... (5.1)
$$R \equiv V / I$$

but we can also define the *Dynamic* (or *Differential*) *Resistance*

... (5.2)
$$r \equiv \frac{dV}{dI}$$

For most materials the current is simply proportional to the applied voltage and these two ways of specifying resistance are indistinguishable. Such materials are said to obey *Ohm's Law*. Looking at the *I/V* plot illustrated in figure 5.1 we can see that this material is <u>not</u>*Ohmic*. In general, the current tends to rise with increasing voltage, but there is a region between the *peak voltage*, V_{peak}, and *valley voltage*, V_{valley}, where the the current <u>falls</u> as the voltage is increased. This is called the *Negative Resistance Region* because in this voltage range the dynamic resistance, $r < 0$. Note, however, that the static resistance is always positive. For this reason, although it is conventional to call this effect 'negative resistance' it should more strictly be called *Negative Differential Resistance* or *Negative Differential Conductance*. The peak voltage is often called the *Threshold* voltage since it represents a threshold we have get over to reach the negative resistance region.

The usefulness of negative resistance can be understood by considering the circuits shown in figure 5.2. Fig 5.2a shows a standard series resonant *RLC* arrangement. Using a.c. circuit analysis we can say that the total voltage around the *RLC* loop will be

... (5.3)
$$0 = \frac{d i\{t\}}{dt} L + i\{t\} R + \int \frac{i\{t\}}{C} dt$$

This equation can be solved to obtain the result that the current around the loop must be of the general form

... (5.4)
$$i\{t\} = \mathrm{Exp}\{At\}$$

where

... (5.5)

$$A = \frac{-R \pm \sqrt{R^2 - 4L/C}}{2L}$$

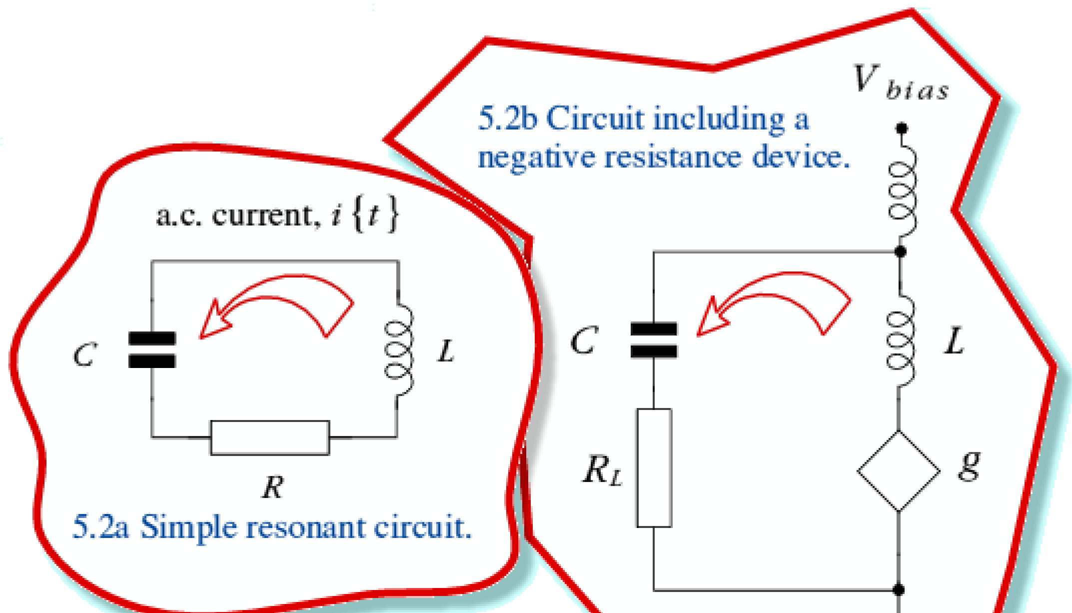


Figure 5.2 Negative resistance oscillator.

Here we will concentrate on what happens when $R^2 < 4L/C$. When this condition is satisfied the part of expression 5.5 inside the root is negative and hence A is complex. We can then say that the current variations will take the form

... (5.6)

$$i\{t\} = \text{Exp}\{\alpha t\}\,\text{Exp}\{j\omega t\}$$

where

... (5.7)

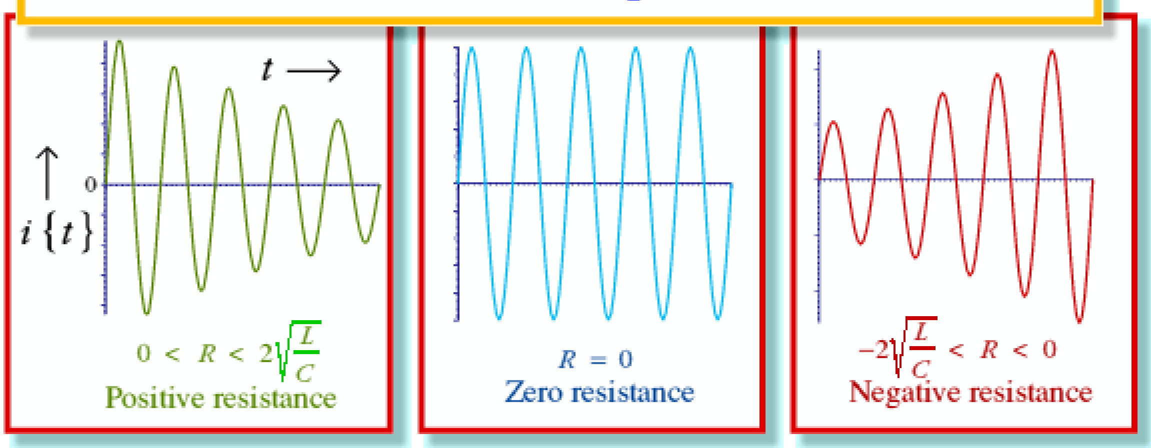
$$\alpha = \frac{-R}{2L} \quad ; \quad \omega = \left|\frac{\sqrt{R^2 - 4L/C}}{2L}\right|$$

Figure 5.3 illustrates how the current in the circuit varies with time when we start with an initial non-zero current, $i\{0\}$. In each case the current can be see to oscillate sinusoidally with the angular frequency, ω, and the amplitude of the oscillation varies

exponentially with time in a way which depends upon the resistance.

In most situations the circuit resistance will have a positive value. This means that α is negative and the oscillation's amplitude declines exponentially as time passes. In effect, the circuit starts with an amount of energy stored in the inductance by the starting current, $i\{0\}$. As time passes this energy is dissipated by the resistor. The oscillation energy fades away and the resistor warms up. However, if we can arrange for the resistance to be zero, the initial current starts an oscillation whose amplitude remains unchanged as time passes. None of the oscillation energy is ever dissipated.

5.3 Effect of resistance value/sign on current oscillation.



A negative resistance value means that α is positive. This means the oscillation amplitude and energy grow exponentially with time. In practice, we can't ever obtain an oscillation whose energy grows larger without limit. Infinite powers and energies aren't accessible in the real world! Something always restricts the rate at which the system can ‘create’ oscillation power. Fairly obviously, this power must also come from somewhere!

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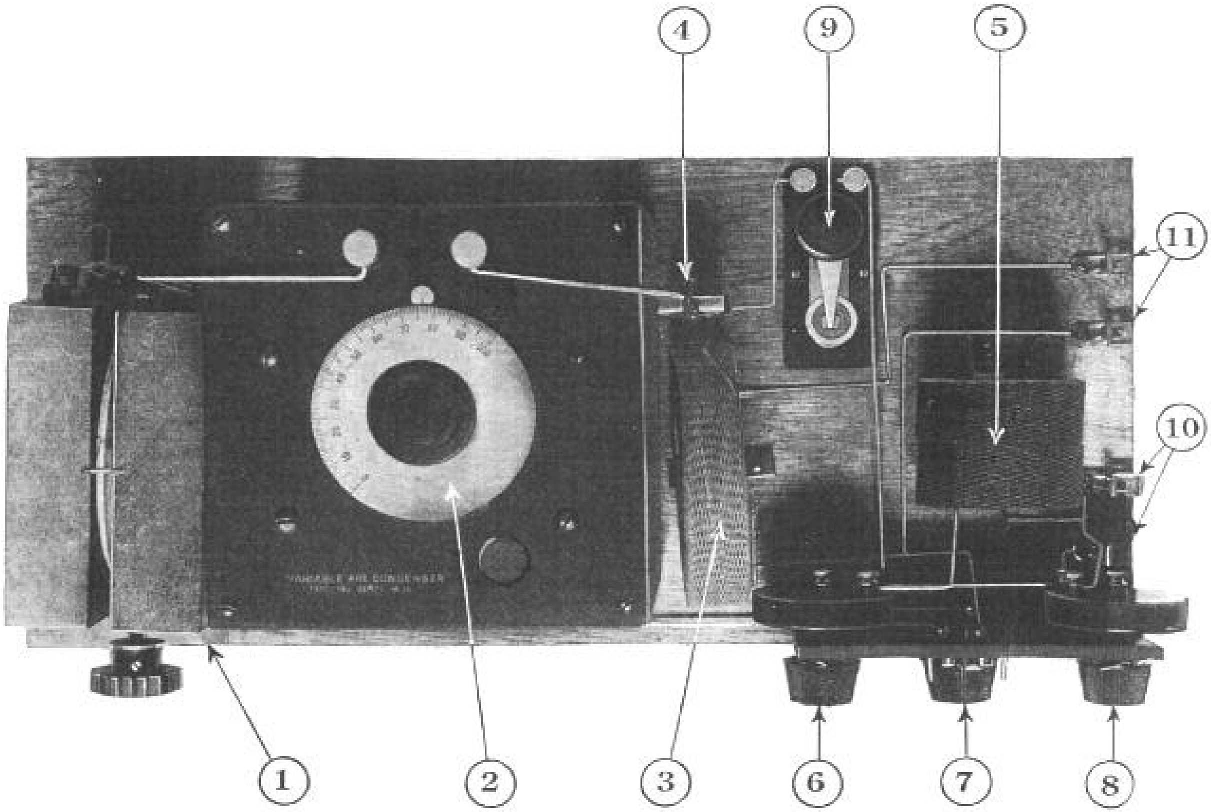
The Crystodyne Principle



Top view of the experimental panel, built in the Radio News Laboratories, to produce oscillations with a crystal detector. In the picture the numbers refer to the following parts: No. 1, variometer; 2, variable condensor; 3, honeycomb coil; 4, .005 mfd. condensor; 5, choke coils; 6, potentimeter; 7, switch; 8, resistance; 9, zincite steel crystal detector; 10, phone clips; 11, battery clips.

SEVERAL experimenters have observed that some contacts, such as crystal and metal or crystal and carbon generally employed as detectors may produce undamped oscillations of any frequency, exactly as the vacuum tube oscillator. The same contact may also be utilized as an amplifier. Oscillating crystals are not new since they were investigated as far back as 1906 by well known engineers, but it was not until lately that a Russian engineer, Mr. O. V. Lossev, succeeded in finding some interesting uses for oscillating crystals. The construction of the apparatus by means of which oscillations may be produced with crystal as a generator seems quite simple and should be of great interest to our readers.

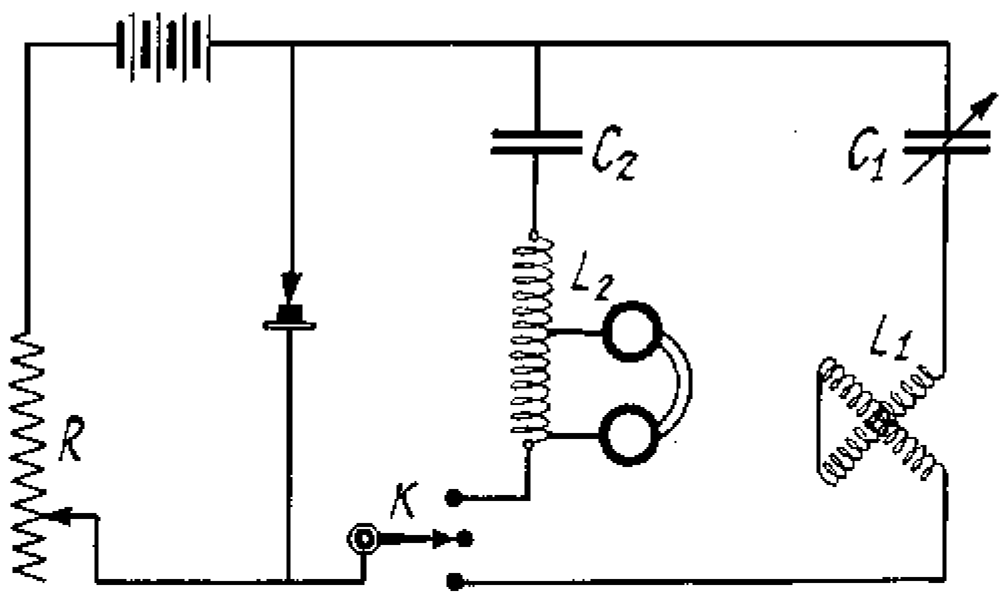


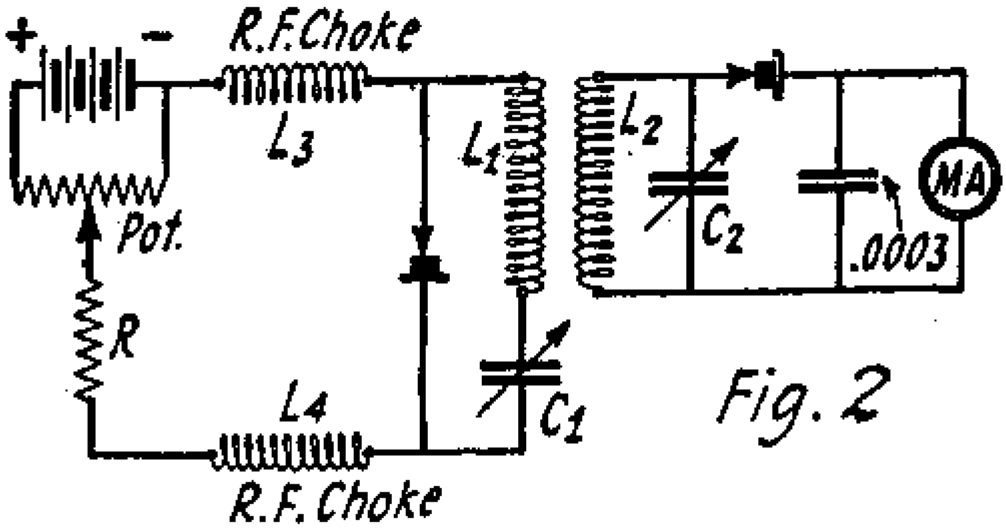
Fig. 1

Diagram of the oscillating crystal circuit. As may be seen, the hook-up is similar to that of an arc transmitter.

Among the numerous contacts studied are pyrite carbon, chalcopyrite-zinc, galena-carbon, or zincite-carbon. The zincite-carbon and zincite-steel contacts seem to be the best producers of strong oscillations. The construction of the contact is similar to an ordinary crystal detector in which a springy piece of wire rests on a crystal. One may use as the cat-whisker a piece of carbon taken from a broken incandescent lamp, the carbon being a piece of the filament; an ordinary piece of steel wire is also suitable.

The zincite crystals may be selected but it has been proved by experiment that even a poor crystal is made much better if it is fused in an arc and scraped to remove the outside black layer which is not a good conductor. One may also break the crystal and use the inside surface. It is necessary to fuse the crystal in binoxide or peroxide of manganese.

To find the best condition in which to use the crystal, one may trace its characteristic curves showing that when submitted to a certain voltage the contact acts as a negative resistance. This negative resistance explains why the crystal may be used to produce oscillations. These curves are generally similar to that of an arc or a dynatron tube. However, it is simpler to try the contact as in an ordinary detector until it functions as an audio frequency oscillator, furnishing a musical note which is heard directly in the phones. Once the crystal oscillates at audio frequency, it is easy to replace the audio frequency circuit by one of radio frequency so as to have the contact



The amount of energy produced by the oscillating crystal may be measured with a microammeter connected as shown in this diagram.

functioning in the ordinary heterodyne manner.

BATTERY FURNISHES POWER

Fig. 1 shows the connection of a circuit which is made to oscillate by the energy produced from a crystal connected to a battery. The battery may be composed of dry cells such as a "B" battery, provided its inside resistance is not too great. The voltage to apply on the contact is generally between 5 and 30 volts, depending upon the quality of the crystal. In the circuit of Fig. 1, the constants are as follows: R is a rheostat of about 3,000 ohms resistance with variable contact. L2C2 is the audio frequency oscillating circuit while L1C1 is the radio frequency circuit. By means of a switch K, either of these may be connected to the crystal. L2 may be a 1-henry inductance; C2, a 2-mfd. condenser; C1, a .01-mfd. condenser; and L1, a 5-millihenry variable inductance. It is preferable to use phones of about 300 ohms resistance in this circuit. By connecting the circuit L2C2, and by varying the tension of the battery and the value of the resistance R, audio frequency oscillations are produced in the circuit. In order to start the radio frequency oscillations in the circuit L1C1, it is necessary to have an extra switch-point not connected to the circuit between the two extreme ones. It is also necessary to have the high frequency resistance of the circuit L1C1 lower than that of L2C2; it is further necessary that the ratio of the co-efficients of self-inductance in the two circuits be equal to the ratio of their respective capacities. It is possible to keep the proper value of inductance and capacity at all times by using a variometer for the inductance L1, and by mounting on the same shaft the variable condenser C1 so that both are turned at the same time, making the ratio between L1 and C1 about constant for any setting.

With the circuit of Fig. 2, it has been found possible to produce oscillations of very high frequency, the shortest wave-length obtained being 25 meters. The resistance R has a value of 2,300 ohms. The coil L1 is 2¼ inches in diameter and is composed of seven turns of No. 12 copper wire. The variable condenser C1 has a value of .0003 mfd. and L3 and L4 are choke coils used to prevent the high frequency oscillations flowing through the battery circuit. To measure the wave-length, a special wave-meter was used, composed of a coil L2 which is 2¼ inches in diameter and consists of a single turn of No. 12 copper wire shunted by a variable air condenser C2 of .006 mfd. capacity. A galena crystal detector is connected in series with a micro-ammeter, with a scale of zero to 100, allowing the operator to find the resonance point.

However, the production of short wave-lengths even with this arrangement is rather difficult although oscillations of lower frequency may readily be produced with the same circuit. We shall show in another article how the zincite crystal oscillator may be used for the reception of code

signals and radio telephony, and how the same crystal may be utilized as an amplifier and detector.

GALENA WEAK OSCILLATOR

Some crystals, such as galena, do not produce strong oscillations, although they may sometimes oscillate sufficiently even without any battery in the circuit to produce a beat note when continuous wave signals or a carrier wave are received. This phenomenon, which has been observed several times, explains why some amateurs using only a crystal detector, are sometimes able to receive continuous waves without an outside oscillator. It also explains how it is sometimes possible to pick up very distant broadcast stations on a crystal set installed in such a location that no radiating receivers or re-radiating structures reinforce the signal. Fig. 3 shows a practical circuit for the reception of short wave C.W. signals with an oscillating crystal similar to the one described above. The crystal may be made to oscillate first by the method explained previously; that is, by listening in the phones when it oscillates at audio frequency, then by means of switches the circuit of Fig. 3 may be connected to the crystal. It should be noted that the potentiometer acts as a vernier when adjusted, because the natural period of the crystal depends upon the bend of the negative part of the characteristic curve; that is, the wave-length decreases if the negative resistance increases. For short wave-length, it is recommended to use a fixed condenser of .003 or .004 mfd. across the detector. This arrangement was used by Fuller who connected fixed condensers across his arcs to improve the efficiency and stability of the circuit.

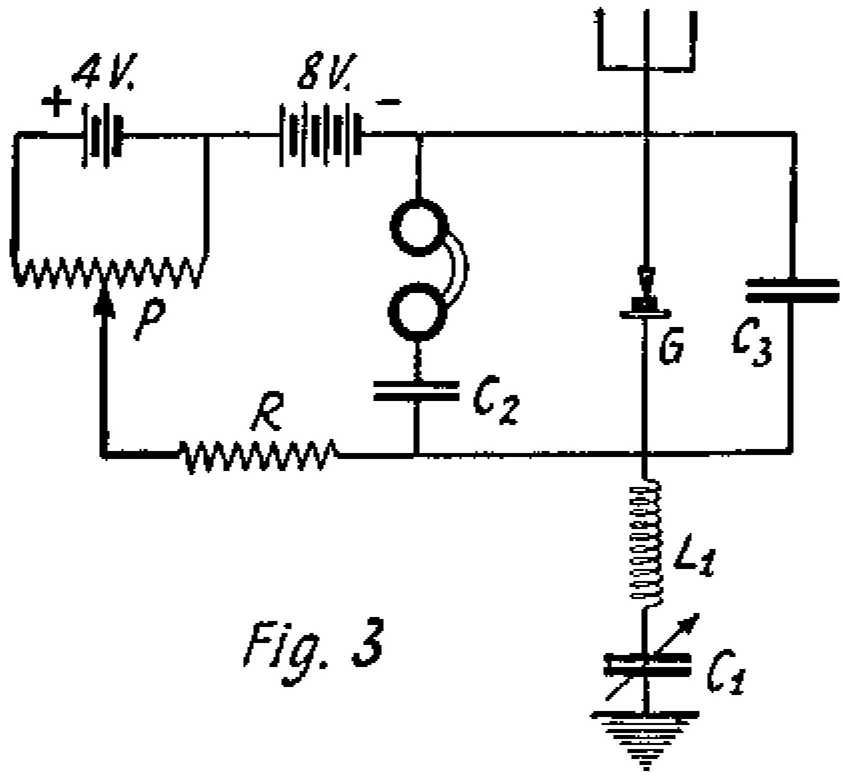
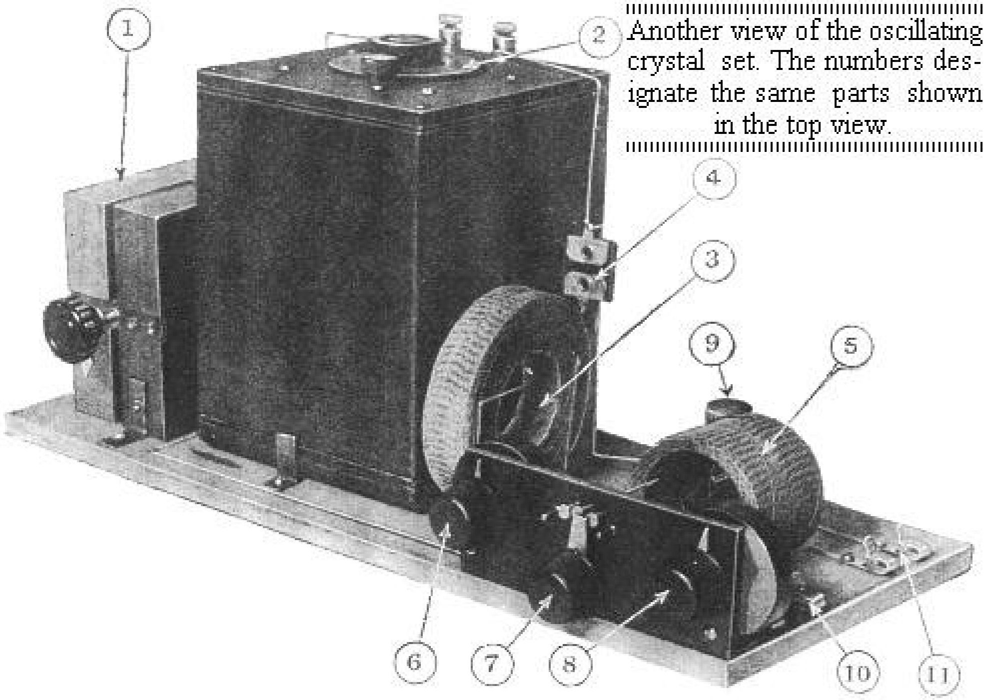


Fig. 3

A practical receiving circuit for the reception of continuous waves with a crystal detector.

It is possible to obtain regeneration with this system by adjusting the potentiometer until the detector starts to oscillate. It is found that a strong increase of the signal strength may be obtained just below the oscillating point exactly as in a regenerative circuit. Mr. Lossev also constructed a small transmitter with such crystal contacts and since he gave the information regarding the circuit to a few amateurs in Russia, they have been communicating over short distances by means of oscillating crystal transmitters. The reception is made by means of oscillating crystals connected as in Fig. 3. The circuits shown herewith are very simple ones which may, of course, be improved upon by experimenters interested in this subject, and we shall welcome any report of results obtained by our readers with oscillating crystals.

In closing, we wish to acknowledge our indebtedness to our French contemporaries *Radio Electricité* and *Radio Revue* for the information contained in this article.



Another view of the oscillating crystal set. The numbers designate the same parts shown in the top view.

THE diagrams, as well as a good deal of the information printed in this article, are published in conjunction with *"Radio Revue"* of Paris. Arrangements have also been made with the inventor, Mr. O. V. Lossev, to furnish additional information on the *Crystodyne* principle.

THE term *"Crystodyne"* has been trade-marked by RADIO NEWS in the United States as well as in Europe. Manufacturers and the trade are cautioned not to use it on any merchandise without the consent of RADIO NEWS.

A Sensational Radio Invention

By HUGO GERNSBACK

REAL radio inventions are very scarce these days. As a rule the latest radio sensation proves to be an adaptation of something that existed before, worked into a novel form. When we, therefore, speak of a sensational radio invention we are aware of the fact that we are using a pretty strong term. Nevertheless, we mean just that. We refer this month to the epoch-making invention of Mr. O. V. Lossev of the Government Radio Electrical Laboratory of Russia.

Stated in a few words, the invention encompasses an *oscillating crystal*. A special form of crystal in a special arrangement is now made to oscillate just exactly as does a vacuum tube. It is now not only possible by means of this invention to receive radio impulses, but to generate and transmit radio waves as well, all by means of the little ubiquitous crystal. In other words, THE CRYSTAL NOW ACTUALLY REPLACES THE VACUUM TUBE. That this is a revolutionary radio invention need be emphasized no further.

Dr. Pickard, in this country, we believe, was the first to produce a crystal circuit that actually oscillated. RADIO NEWS in December, 1923, published an account of this exploit. Mr. Pickard, however, was never able, to the best of our knowledge, to obtain worthwhile results from his arrangement. Mr. Lossev, on the other hand, has gone quite deeply into the problem and has solved all the difficulties that lay in his path, in a very brilliant manner.

Two of the greatest German authorities, Count Arco and Dr. Meisner, recently visited Mr. Lossev's laboratory. They not only marveled at Mr. Lossev's invention, which is as novel as it is simple, but they were also greatly astonished by the youth and talent of the inventor.

From what has been said it will be understood now that he oscillating crystal which RADIO NEWS has termed the *Crystodyne Principle* can be used in exactly the same manner as any existing vacuum tube. We can not only detect with the crystal, but we can also amplify with it. We may use any number of them in various circuits in order to bring in great distance or to obtain greater power, the same as we do now with the multiple tube sets. In a short time we may speak of *three or six crystal sets*, the same as we speak now of a three or six tube set.

Just as we can transmit radio impulses by means of continuous waves using the vacuum tube, we can now also transmit with the *Crystodyne*, and, as a matter of fact, a number of students in Russia have actually sent messages with such sets over distances of more than three-quarters of a mile during the past few months.

As a side-light of all this, it should be noted that the Editor has always featured the crystal wherever it was possible. He knew that sooner or later just this thing would come about. His many past editorials on the crystal bear witness to this. The oscillating crystal also explains now how some radio experimenters have been able to obtain such remarkable long distance records with crystal outfits. It would seem that wherever these records were made, the crystal actually oscillated in one way or another without the user being aware of it.

A curious fact about the new *Crystodyne Principle* is that it operates exactly as an arc transmitter. While at present only the crystal *zincite* in connection with a *steel point* gives the real results, there is no question but that other combinations will be found that will work even better. The thousands of friends of the crystal, when they get busy, will in time no doubt, find the correct measures to produce oscillations from other combinations.

That the radio industry is due for an entire revolution through this invention there seems to be no question. But like other revolutionary inventions, the revolution, as a rule, does not come over night. It will take many years for the *Crystodyne Principle* to be adopted in our radio sets. Three to five years may be necessary before that is brought about.

Right here we must sound a note of caution. It must be understood that, for the present, the invention is practically confined to the laboratory and the up-to-date experimenter. *It has not become perfected sufficiently to enter into the commercial stage.* This lies in the future. As wonderful as the invention is, it still has all the troubles and weaknesses of the crystal. There is the usual cat-whisker contact and the usual elusive sensitive spot. Once the contact is adjusted the *Crystodyne* works well, but a knock or jar may put the circuit out of commission.

If you had a Super-Heterodyne using the *Crystodyne Principle* incorporating from six to eight crystals, the job of keeping all of them in operation would be a rather difficult one. Of course, vacuum tubes have not this weakness, although they have others. But for surety of operation the vacuum tube today is supreme. It may take many years for the oscillating crystal to be perfected in such a manner that it will supercede the vacuum tube, but we predict that such a time will come.

Future improvements of the *Crystodyne* will probably be along the following lines: perhaps in some form of a synthetic crystal or perhaps some crystal arrangement in a vacuum that is just as fixed as is the present day vacuum tube. There will then of course be no necessity for cat-whiskers and adjusting means.

The future *Crystodyne* receiving set will therefore be rather small, there being no "A" battery required, all the "B" battery voltage being taken from small flashlight batteries which fit right into the set. Such an outfit would require a good deal less room than the present day outfits.

In the meanwhile, the Seventh Heaven has been opened up to all dyed-in-the-wool radio experimenters. RADIO NEWS hereby makes it its business to bring to its readers, from month to month, all the new developments of the *Crystodyne Principle.*

How Do Transistors Work?

NO, HOW DO THEY *REALLY* WORK?

Page 1, Page 2 La versión Español. Short version Help Translate!

Most introductory textbooks do a very poor job of explaining the details transistors' internal workings. First they assume that the Base current is somehow controlling the Collector current, then they try to explain how

one current can affect another. These explanations always fail because Bipolar transistors, like FETs, are voltage-controlled devices. One current **doesn't** affect another. Instead, the Base-Emitter voltage controls the thickness of an insulating "depletion layer" which lies in the path of both the Base current and the larger Collector current.

NOTE: This article delves into bipolar transistor internal operation: it's the physicist's viewpoint; not the engineer's or technician's. While solving design problems, engineers must model the transistor as a current amplifier, or as a transconductance device, or as a charge-controlled current source. If you want to understand a transistor circuit, then the black-box model is what you want. But be warned, because if our goal instead is to "open the hood" and see what's really going on inside, those useful black-box models can derail our understanding.

When I first became interested in electronics as a kid, I sat down and figured out how bipolar transistors work.

Well, sort of.

I read many articles which explained the "Common Base" amplifier. Common-base is the setup which was used by the inventors of the transistor. In those explanations, the Base is a grounded piece of Germanium and the input signal is applied to the Emitter. Since common-base amplifiers are rarely used in transistor circuitry, I ended up having to dream up my own explanation. I based it upon the little bits I already knew about the Common Emitter configuration. Common Emitter the one where the Emitter is grounded, the Base is the input, and where the output is taken across a resistor connected to the Collector. My home-made explanation sort of worked, but I wasn't satisfied. I was full of niggling doubts. And why the hell were the textbooks using Common Base to introduce transistors to the newbies? It just didn't make any sense.

When I went into engineering school, I found it extremely odd that there were *still* no good explanations of bipolar transistors. Sure, there were detailed mathematical treatments. Just multiply the Base current by "hfe" to obtain the Collector current. Or, treat the transistor as a two-port network with a system of equations inside. Ebers-Moll and all that. But these were similar to black-box circuits, and none of them said HOW a transistor works, *how can a small current have any effect on a larger one????* And nobody else seemed curious. Everyone else in the class seemed to think that to memorize the equations was the same as learning concepts and gaining understanding of the device. (R. Feynman calls this the Euclidean or "Greek viewpoint;" the love of mathematics, as opposed to the physicists' " Babylonian viewpoint" where concepts are far more important than equations.) I'm a total Babylonian. For me, math is useless

at the start, equations are like those black box Spice programs which might work great, but they don't tell you any details of what's happening inside a device in the real world. First tell me what "Transistor Action" is all about. Show me animated pictures, use analogies. Only after I've attained a visual and gut-level understanding of something, only then is the math useful to me for refining it and adding all the details. However, math alone is not a genuine explanation. Math is just a tool or a recipe, a crutch for those who want nothing except the final numerical result, and it certainly does not confer expert knowledge.

Now many years have passed and I think I see the problem...

Traditional transistor explanations basically *suck.*

The ones I see in textbooks and hobby magazines are terrible. They're full of errors and contradictions. They misuse the word "current" as if it were a substance that flows. They don't explain insulators properly. And they try to prove that the base current can have an effect on the collector current. And then there's all those authors who use Common-base amplifiers to introduce transistors to newbies. Are they just fools who follow a tradition only because it's traditional? Why don't they ever make efforts to *improve* the explanations? Were they written in stone by god? Well, if nobody but me thinks the explanation is open to improvements, then I'd better put my money where my mouth is. (And if I'm right, then it should be very easy to write a vastly improved explanation.)

Below are my ideas on how transistors *really* work. They're *not* based on the traditional explanations found widely in engineering texts and electronics magazines. Instead they're based on semiconductor physics and the details behind the Ebers-Moll model. As you'll soon see, several new concepts are required. It might be easier for you to just memorize the equations rather than to imagine what really goes on inside. But if you DO manage to decode my explanations and crude ASCII artwork, I think you'll be in the elite minority who *really understands* transistors. I've found that even most working engineers have no good mental picture of bipolar transistor operation. So, if you attain a clear understanding of transistors, you'll surpass many of the experts.

First of all, you must abandon the idea that *current* travels in transistors or flows inside of wires. Yes, you heard me

right. Current does not flow. Electric current *never* flows, since an electric current is not a stuff. Electric current is a flow of something else. (Ask yourself this: what's the stuff that flows in a river, is it called "current?" Or is it called "water?")

Since a current is a flow of charge, the common expression "flow of current" should be avoided, since literally it means "flow of flow of charge." - MODERN COLLEGE PHYSICS, Richards, Sears, Wehr, Zemanski

So what flows inside of wires?

The stuff that moves within wires is not named Electric Current. Intead it is called **Electric Charge**. It's the **charge** that flows, never the current. And in rivers or in plumbing, it's the water that flows, not the "current." We cannot understand plumbing until we stop believing in a magical stuff called "current." We must learn that "water" flows inside of pipes. The same is true with circuits. Wires are not full of current, they are full of charges that can move. Electric charge is real stuff; it can move around with a real velocity and a real direction. But electric current is not stuff. If we decide to ignore "current," and then examine the behavior of moving charges in great detail, we can burn off the clouds of fog that block our understanding of electronics.

Second: the charges found within conductors do not push themselves along, but instead they're pushed by potential difference; they're pushed by the voltage-fields within the conductive material. Charges are not squirted out of the power supply as if the power supply was some sort of water tank. If you imagine that the charges leave through the positive or negative terminal of the power supply; and if you think that the charges then spread throughout the hollow pipes of the circuit, then you've made a fundamental mistake. Wires do not act like "empty electron-pipes." A power supply does not supply any electrons. Power supplies certainly *create* currents, or they *cause* currents, but remember, we're removing that word "current." To create a flow of charges, a power supply *does not* inject any charges into the wires. The power supply is only a pump. A pump can supply a pumping pressure. Pumps never supply

the water being pumped.

Third: have you discovered the big 'secret' of visualizing electric circuits?

ALL CONDUCTORS ARE ALREADY FULL OF CHARGE

Wires and silicon ...both behave like pre-filled water pipes or water tanks. Electric circuits are based on full pipes. This simple idea is usually obscured by the phrase "power supplies create current," or "current flows in wires." We end up thinking that wires are like hollow pipes. We end up thinking that a mysterious substance called Current is flowing through them. Nope. (Once we get rid of that word "current," we can discover fairly stunning insights into simple circuits, eh?)
If circuits are like plumbing, *then none of the "pipes" of a circuit are ever empty.* This idea is extremely important, and without it we cannot understand semiconductors ...or even conductors. Metals contain a vast quantity of movable electrons which forms a sort of "electric fluid" within the metal. A simple block of copper is like a water tank! Physicists call this fluid by the name "electron sea of metals." Semiconductors are always full of this movable "charge-stuff." The movable charge is there even when a transistor is sitting on the shelf and disconnected from everything. When a voltage is applied across a piece of silicon, those charges already within the material are driven into motion. Also note that the charge within wires is ...uncharged. Every movable electron has a positive proton nearby, so even though the metal contains a vast sea of charge, there is no net charge on average. Wires contain "uncharged" charge. Better call that "cancelled charge." Yet even though the electrons are cancelled by the protons, the electrons can still flow among the protons. Cancelled charge can still move around, so it's possible to have flows of charge in uncharged metal.

OK, since the "pipes" are already full of "liquid," then in order to understand circuitry we should NOT trace out the path starting at the terminals of the power supply. Instead, we can start with any component on the schematic. If a

voltage is applied across that component, then the charges within that component will start to flow. Let's modify the old "flashlight explanation" which we all were taught in grade school. Here's the corrected version:

AN ACCURATE FLASHLIGHT EXPLANATION:
Wires are full of vast amounts of movable electric charge (all conductors are!) If you connect some wires into a circle, you form an "electric circuit" which contains a movable conveyor-belt made of charges within the metal. Next we cut this circle in a couple of places and we insert a battery and a light bulb into the cuts. The battery acts as a charge pump, while the light bulb offers friction. The battery pushes the wires' row of charges forward, then all the charges flow, then the bulb lights up. Let's follow them.

The charges start out inside the light bulb filament. (No, not inside the battery. We start at the *bulb*.) The charges are forced to flow along through the filament. Then they flow out into the first wire and move along to the battery's first terminal. (At the same time more charges enter the filament through its other end.) The battery pumps the charges through itself and back out again. The charges leave the second battery terminal, then they flow through the second wire to the bulb. They wind up back inside the light bulb filament. At the same time, the charges in other parts of the circuit are doing the same thing. It's like a *solid belt* made out of charges. The battery acts as a drive wheel which moves the belt. The wires behave as if they hide a conveyor belt inside. The light bulb acts like "friction;" getting hot when its own natural charges are forced to flow along. The battery speeds up the entire belt, while the friction of the light bulb slows it down again. And so the belt runs constantly, and the light bulb gets hot.

The truth will set you free ...but first it will piss you off!
-anon

Brief review:

1. THE STUFF THAT FLOWS THROUGH CONDUCTORS IS CALLED CHARGE. ("CURRENT" DOESN'T FLOW.)

2. THE CHARGE INSIDE CONDUCTORS IS SWEPT ALONG BY VOLTAGE FIELDS.

3. ALL WIRES ARE "PRE-FILLED" WITH A VAST AMOUNT OF MOVABLE CHARGE

4. BATTERIES AND POWER SUPPLIES ARE CHARGE-PUMPS.

5. LIGHT BULBS AND RESISTORS BOTH ACT "FRICTIONALLY."

One last thing: The difference between a conductor and an insulator is simple: conductors are like pre-filled water pipes, while insulators are like pipes choked with ice. Both contain the "electric stuff;" conductors and insulators both are full of electrically charged particles. But the "stuff" inside an insulator can't move. When we apply a pressure-difference along a water pipe, the water flows. But with an empty pipe, there's nothing there, so the flow does not occur. And with an ice-choked pipe, the stuff is trapped and doesn't budge. (In other words, voltage causes charge-flow in conductors, but it can't cause charge-flow in insulators because the charges are immobilized.) Many intro textbooks get their definitions wrong. They define a conductor as something through which charges can flow, and insulators supposedly block charges. Nope. Air and vacuum don't block charges, yet air and vacuum are good insulators! In fact, a conductor is something that contains movable charges, while an insulator is something that lacks them. (If a book gets this foundational idea wrong, then most of its later explanations are like buildings built on a pile of garbage, and they will collapse.)

One more last thing before diving into transistors. *Silicon is very different than metal.* Metals are full of movable charges... but so is doped silicon. How are they different? Sure, there's that matter of the "band gap," and the difference between electrons versus holes, but that's not the important thing. The important difference is quite simple:

metals have vast quantities of movable charge, but silicon has far less. For example in copper, every single copper atom donates one movable electron to the "sea of charge." Copper's "electric fluid" is very dense; just as dense as the copper metal. But in doped silicon, only one in every billion atoms donates a movable charge. Silicon is like a big empty space with an occasional wandering charge. In silicon, you can sweep all the charges out of the material by using a few volts of potential, while in a metal it would take billions of volts to accomplish the same thing. Or in other words:

6. THE CHARGE INSIDE OF SEMICONDUCTORS IS LIKE A COMPRESSIBLE GAS, WHILE THE CHARGE INSIDE OF METALS IS LIKE A DENSE AND INCOMPRESSIBLE LIQUID.

Sweeping away the charges in a material is the same as converting that material from a conductor to an insulator. If silicon is like a rubber hose, then it's a hose which contains compressible gas. We can easily squeeze it shut and stop the flow. But if copper is also like a rubber hose, then instead, it's like a hose full of iron slugs. You can squeeze and squeeze, but you can't smash them out of the way. But with air hoses and with silicon conductors, even a small sideways pressure can pinch the pathway shut and stop the flow.

OK, let's look at the way that transistors are usually explained.

To turn on an NPN transistor, a voltage is applied across the base and emitter terminals. This causes electrons in the Base wire to move away from the transistor itself and flow out towards the power supply. This in turn yanks electrons out of the P-type base region, leaving 'holes' behind, and the 'holes' act like positive charges which are pushed in the opposite direction from the direction of electron current. What SEEMS to happen is that the base wire injects positive charges into the base region. It spews holes. It injects charge.

(Note that I'm describing *charge flow* here, not positive-charge "conventional current.")

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        _______|______
       |              |
       | COLLECTOR N  |
       |______________|
ELECTRONS ARE PULLED FROM THE
       |              |  ----->               BASE
REGION AND INTO THE WIRE,
       | BASE      P  |______________         WHICH
CREATES POSITIVE "HOLES"
       |______________|              |  +     WHICH
SPEW OUT INTO THE BASE
       |              |           ___|___     REGION.
       | EMITTER   N  |             _____
       |______________|          _________
               |                    _____
               |_____________________|  -
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That's part of the conventional explanation. Why is all of this important to transistor operation? ****It's not*!*** The base current is not important to transistor operation. It's just a byproduct of the REAL operation, which involves an insulating layer called the Depletion Region. By concentrating on the current in the Base lead, most authors go up a dead end in their explanations. To avoid this fate, we must start out by ignoring the base current. Instead we look elsewhere for understanding. See the diagram below.

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        _______|______
       |              |           \
       | COLLECTOR    |           |
       |              |            > full of wandering
electrons
       |  n-doped     |           |
       |______________|          /
       |              |               \
       | BASE         |               |
       |              |--              > full of
wandering "holes"
       |  p-doped     |               |
       |______________|              /
       |              |      \
       | EMITTER      |      |
       |              |       > full of wandering
electrons
       |  n-doped     |      |
       |______________|     /
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                |
The Depletion Region is an insulating layer existing
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The Depletion Region is an insulating layer existing between the base region and the emitter region. Why is it there? It exists because the Base region is p-doped silicon; the insulating layer appears because p-type silicon is full of naturally-occurring movable "holes," and because the p-type silicon is touching n-type silicon.

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                |
         _______|_______
        |               |
        |  COLLECTOR N  |
        |_______________|
        |               |
        |  BASE      P  |--
        |_______________|
         _______________    <-- insulating "depletion
layer"
        |               |
        |  EMITTER  N   |
        |_______________|
                |
                |
```

The Depletion layer appears when electrons fall into holes. The p-type silicon has electrons too, but they act like the closely-packed beads of an abacus, and the "holes" are like gaps in the rows of beads. Move one bead, and a hole has moved the other way. Touch the p-type silicon against the n-type, and lone wandering electrons from the n-type silicon will fall into the holes. Also, holes in the p-type's Base region can flow out among the movable electrons from the N-type Emitter region and many swallow electrons and are cancelled. Holes eat electrons, and this leaves a thin region between N and P sections which lacks movable charges.

Remember: a conductor is *not* a substance which allows charges to pass. (Don't forget #3 above!) Actually a conductor is any substance which contains charges which are *movable.* Anything that lacks movable charges is an insulator. Inside the depletion layer, all the opposite charges have fallen together and vanished. The gaps in the abacus beads are gone, so no beads can move anymore. It's packed solid with immobile charges, so the silicon has turned into an insulator. When there's no voltage applied across the base/emitter terminals, this insulating layer

grows fairly thick, and the transistor acts like a switch which has been turned off.

I like to visualize that a transistor's silicon as normally like a shiny silver conductor (sort of like metal) ...except for that insulating layer between the P and N regions which acts more like a layer of insulating glass. Silicon is like a metal which can become glass!

```
                |
         ______|______
        |             |              \
        | COLLECTOR N |              |
        |_____________|              >   Shiny silver conductive
        |             |              |
        | BASE      P |--            /
        |_____________|
         _____________      <-- Glasslike insulating "depletion layer"
        |             |         \
        | EMITTER  N  |         >   Shiny silver conductive
        |_____________|         /
                |
                |
```

Whenever voltage is applied between base and emitter, this insulating layer *changes thickness.* If (+)voltage is applied to the p-type (to the base wire,) while a (-) voltage polarity is applied to the n-type, (to the emitter wire,) then electrons in the n-type are pushed towards the holes in the p-type. The insulating layer becomes so thin that the clouds of electrons and holes start meeting and combining. A current therefore exists in the base/emitter circuit. But this current is not important to transistor action. What's important to notice is that the *VOLTAGE* across the base/emitter has caused the insulating Depletion Layer to become so thin that the charges can now flow across it. It's as if the transistor contains a layer of glass whose thickness can be varied when we alter a Base-Emitter voltage. The layer becomes thinner when BE voltage is increased. This happens because the voltage pushes the holes and the electrons towards each other, reducing the size of the empty insulating region between the clouds of holes and electrons, and allowing the stragglers to jump across the insulator. The depletion layer is a voltage-controlled switch

which "closes" when the right polarity of voltage is applied. It is also a *proportional* switch, since a small voltage can close it only partially. For silicon material, charges first start jumping across when the voltage is around 0.3V. Raise the voltage to 0.7V and the current gets very high. (That's for silicon. Other materials have different turn-on voltages.) The larger the voltage, the thinner the insulating layer, so the higher the current in the entire transistor. By applying the right voltage, we can thicken or thin the depletion layer as desired, creating an open, closed, or partially open switch.

See what's happening here? *The transistor is not controlled by current.* Instead it is controlled by the base/emitter voltage.

7. THE P-TYPE AND N-TYPE ARE CONDUCTORS BECAUSE THEY CONTAIN MOVABLE CHARGES.

8. A LAYER OF INSULATING MATERIAL APPEARS WHEREVER P-TYPE AND N-TYPE TOUCH.

9. THE INSULATING LAYER CAN BE MADE THIN BY APPLYING A VOLTAGE.

```
               |
         ______|______
        |              |
        | COLLECTOR N  |
        |______________|
        |              |   ---->
        | BASE       P |_______________________
        |=============|              |   +       With a small voltage applied,
        |              |          ____|____       the depletion layer gets thin,
        | EMITTER   N  |            _____         charges start crossing it,
        |______________|          _________       and a small current appears.
               |                    _____         The "switch" is only partly
               |______________________|   -       closed!
<-----
```

OK, on to PART TWO

Also see: short version of article
and the versiónEspañol.

PS

The transistor was invented around 1923, by physicist Dr. J. Edgar Lilienfeld, the father of the modern electrolytic capacitor. WHAT?!!! But everyone knows that it was invented at Bell Labs in 1947. Nope. The original transistor was a 1920s thin-film device deposited on glass. The base region was a clever idea: crack a piece of glass, put it back together with metal foil clamped in the crack, then slice off the extra foil to make a flat surface that goes: glass, metal, glass. Deposit a thin layer of semiconductor and heat the device, and the thin metal line will "dope" that part of the semiconductor layer. Simple! Dr. Lilienfeld also built MOSFETs using the natural oxide layer found on aluminum plates. He also built a working transistor radio and showed it around to various companies. It was ignored, possibly because he didn't have a solid theory to explain how his invention worked, but more probably because it was weird and new. Some hobbyist should try making a home-built transistor. [*New 2006 info: R. G. Arns says that Bret Crawford built sucessfulLilienfeld transistors in 1991 as his MS Physics Thesis. Joel Ross did it again in 1995 with more stable versions. And more amazing: William Shockley and G. L. Pearson did so in 1948, publishing in Physical Review for July 15 1948, but they concealed the fact that it was Lilienfeld's device they were demonstrating!*]

Lilienfeld's patent numbers are:

- # 1,745,175 Method and Apparatus for Controlling Electric Currents
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Also:

- R. G. Arns"The other transistor: early history of the MOSFET." (.pdf) Engineering Science and Education Journal 7 (5): 233-240 (1988)
- IEEE Spectrum: How Europe Missed the Transistor (independantly invented "transistron")
- T. L. Thomas, Twenty Lost Years of Solid State Physics, Analog (magazine) March 1965

PPS
It is possible to make a transistor using Galena (lead sulfide, PbS). Galena is often available from rock shops and science museum stores. You can even make your own by melting sulfur and lead powder over a flame. Look up keywords such as "cat's whisker diode" and "crystal radio" to find out more.

The trick to making a transistor is to use a hyper-clean, freshly-cleaved crystal face, to sharpen your cat's-whisker contacts by dissolving the tips using electrolysis, and then to put the tips within 0.05mm of each other (or preferably within 0.01mm). Obviously the latter is the hardest part. Better use a microscope! The authors of the following article found that the base/emitter junction was critical: it HAD to act as a good rectifier. The base/collector junction wasn't as important. They got some power gain, but their beta was in the single digits. Others have mentioned that if you break open a 1N34 glass diode to expose the Germanium chip, you can make a crude transistor with a similar procedure. Old Germanium audio power transistors probably do the same, while giving much larger semiconductor area on which to play.

Crystal Triode Action in Lead Sulphide, P. C. Banbury, H.A. Gebbie, C. A. Hogarth, pp78-86. SEMI-CONDUCTING MATERIALS, Conference proceedings, H.K. Henisch (ed), 1951 Butterworth's scientific publications LTD 1951.

HOW DO TRANSISTORS

WORK?
PART II

OK, everything we know is wrong, and transistors aren't really "current amplifiers." <grin> Instead the base voltage is the important thing, not the base current.

```
             |
       ______|______
      |             |
      | COLLECTOR N |
      |_____________|
      |             |  ---->          With a small voltage applied,
      | BASE      P |____________     the depletion layer gets thin,
      |=============|            |  +   charges start crossing it, and
      |             |        ____|____  a small flow of charge appears
      | EMITTER  N  |          _____    in the battery circuit.  The
      |_____________|        _________  "switch" is only partly closed!
             |                 _____
             |___________________|  -
<-----
```

The changing thickness of the insulating depletion layer switches the transistor on and off. And since BASE VOLTAGE is what changes the thickness, we can ignore the current in the base wire. But wait a minute, WHICH flow of charge is being switched on and off? Ah, we have another entire circuit to add to our diagram. We connect another battery across the entire transistor, between emitter and collector. Let's use a common 9-volt battery.

```
<------

            ________________________
           |                        |
           |                        |
           |                        |
           |                  ______|______
           |                 |             |
 Collector |                 | COLLECTOR N |
 Battery   |   +             |_____________|
       ____|____             |             |______________
         _____               | BASE      P |              |
       _________             |=============|              |   +
         _____   9V          |             |          ____|____
       _________             | EMITTER  N  |            _____    Base
         _____               |_____________|          _________  Battery
       _________                    |                   _____     .5V
         _____                      |                     |   -
           |   -                    |_____________________|
           |________________________|

                      ------->
```

So the Base Battery turns on the transistor's "switch", and this lets the 9-volt Collector-Battery drive a large flow of charge vertically through the entire thing.

What use then is the "collector's" silicon? Won't the voltage from the collector battery override control from the base? And why have THREE silicon segments at all? Won't the second Depletion Layer turn everything off? And why not just connect the top wire to the Base section directly?

The answers are in the last of these questions. If we got rid of the collector, we'd accidentally connect the two batteries together, since silicon is a good conductor. We'd end up with a diode instead (see below.) The batteries would fight each other, and the diode would just act like a short circuit between the two batteries.

```
                                      IT'S ALL SHORTED OUT, IT
                                      GETS HOT AND SMOKES
             _____________________    __________________
            |                     |  |                  |
  Collector |                     |  |                  |
  Battery   |    +            ____|__|___               |
        ____|____            |           |              |
          _____              | BASE     P|              |
        _________            |===========|              |   +
          _____   9V         |           |          ____|____
        _________            | EMITTER  N|            _____    Base
          _____              |___________|          _________  Battery
        _________                   |                 _____     .5V
          _____                     | IT'S A PN DIODE   |    -
            |    -                  |                   |
            |_______________________|___________________|
```

Obviously the collector is required. Obviously the collector segment does something really strange!

Notice that the collector battery is applying a (+) polarity to the collector, but the collector is n-type silicon. Isn't this backwards? Won't there be a whole second Depletion Layer forming between collector and base? YES! And since we're using a 9-volt battery to pull the movable holes in the p-type away from the electrons in the n-type, this depletion layer will be a thick one. It should act like a turned-off switch, eh? It does... and yet it doesn't. I personally think this is the strangest part of transistor action, and it took me a good while before my brain stopped rejecting the weirdness so I could "see" it all happening at once.

```
<------

             _______________________
            |                       |
            |                       |
            |                 ______|______
            |                |             |
  Collector |                | COLLECTOR N |
  Battery   |    +           |_____________| thick depletion layer
            |                 _____________
        ____|____            |             |______________
          _____              | BASE      P |              |
        _________            |=============|              |   +
          _____   9V         |             |          ____|____
        _________            | EMITTER   N |            _____    Base
```

```
     _____              |_____________|         _________  Battery
   _________                   |                  _____     .5V
     _____                     |                    |  -
       |   -                   |____________________|
       |_______________________|

               ------->
```

OK, this new depletion layer keeps the Collector Battery from affecting the rest of the transistor. If we increase the voltage of that 9V battery, the insulating layer between Base and Collector segments just gets thicker, and the Base/Emitter segments below the Collector never feel the voltage-force from that battery. Yes, the "upper surface" of the Base segment in the upper depletion zone does feel the force from the 9V battery, but the rest of the circuit does not. (It's like waving a highly-charged balloon near a flashlight's circuit. Nothing happens to the charge flow in the flashlight.)

HOWEVER!

Because the Base battery has already thinned out the insulating emitter depletion layer, this means that swarms of movable electrons can pour from the Emitter and upwards into the Base segment. Only a few will actually flow upwards into the Base, since it would cause a traffic jam if the Base wire wasn't able to immediately suck those electrons out again. (Or more accurately, if the electrons in the Base don't leave again, and aren't cancelled by holes, then any extra electrons would cause the Base segment to become negatively charged, which would repel any more electrons coming upwards from the Emitter.

So now we have a sparse cloud of a few electrons entering the p-type silicon of the Base section from below, and some of those electrons wander upwards into the "upper surface" of the Base segment. What happens? They're suddenly exposed to the attraction of the 9V battery positive voltage.

The upper depletion region doesn't act so much like a hunk of insulating glass, instead it acts like an insulating air gap. It's only insulating if there are no movable charges present. It doesn't block the flow of charges, but if no charges exist there, the voltage cannot create a charge flow.

PS, Don't forget, there were always plenty of holes already in the Base segment, but any holes which dare to wander upwards out of the Base segment will be pushed back down by the positive polarity of the 9V battery. (That's what makes the depletion zone act like an insulator in the first place: it repels holes back into the P, and repels electrons back into the N.) Imagine that the Collector segment is conductive metal. The Base segment is also like a metal, and the depletion region between them is like an empty space. Next, "static electricity" happens!

We've electrically charged the Collector segment to positive 9 volts. Stick some rice-crispies in the empty gap, and if they're negatively charged they'll be sucked upwards. Well, the few wandering electrons in the Base segment act JUST LIKE negatively charged objects, and if they should wander up to the surface of the base layer, up they'll go. They'll be sucked across the gap into the Collector and then forced to go

around the rest of the collector circuit. This can only happen if they get to the "upper surface" of the Base segment. When they were within the Base segment, the Base acted like a conductive metal shield, and the wandering electrons didn't "see" the strong attractive field coming from the Collector segment.

Some electrons are yanked upwards and go missing from the Base. But this relieves the "traffic jam!" The Base region loses some electrons upwards. As soon as the positively charged Collector has yanked some electrons out of the Base segment, more electrons can finally pour in from below... which gives us more wandering electrons to be yanked upwards, and so on. A fairly huge vertical charge flow appears.

The "traffic jam effect," as well as the valve-action of the thin depletion zone between base and emitter, these team up to control the main vertical current through the whole transistor. Any electron which wanders across the very thin Emitter depletion zone can also wander across the thin Base segment and end up becoming part of the large flow of charge in the Collector Battery circuit. The Base Battery voltage controls the width of the thin depletion zone, and this controls the amount of electrons pouring up into the collector. The Collector battery provides the "suction" that drives the main vertical current. But if we change the voltage of the collector battery, the vertical flow of charge does not change. The collector battery only attracts what electrons it's given. It can't alter the collector current. This is an interesting situation known as a "constant current power supply."

Note that it's important to make the Base segment be fairly thin so we maximize the "traffic jam" effect (and minimize the number of charges that unnecessarily leak out of the Base wire.) We're relying on the natural ability of electrons to wander across the Base section all by themselves. No voltage is pushing them in that direction. The Base Battery is pulling them slowly sideways towards the Base wire. The Collector battery can't start yanking on them at all, not until they reach the "upper surface" of the Base segment.

If you make people think they're thinking, they'll love you. But if you really make them think, they'll hate you - Don Marquis

Whew. All the stuff above is a very large chunk to swallow. Don't be suprised if it takes your brain awhile to connect all the puzzle-pieces together. It took me ages to see all of this (and it only happened years after I took two semesters of engineering school focused on the Ebers-Moll mathematical model describing this entire subject.) The voltage-control viewpoint shown by the Ebers-Moll explanation does appear widely in textbooks, but it certainly isn't widely learned. If it had been learned, then people wouldn't get angry when they hear that transistors are voltage-controlled; that the collector current is proportional to the voltage across the base-emitter junction.

We'd better recap:

10. THE TRANSISTOR CAN ACT LIKE A SWITCH (OR LIKE A PARTIALLY-ON SWITCH.)

11. CONNECT A POWER SUPPLY OR BATTERY FROM COLLECTOR TO EMITTER TO CREATE A BIG FLOW OF CHARGE (BUT WHY?)

12. THERE'S ANOTHER DEPLETION ZONE BETWEEN COLLECTOR AND BASE.

13. THIS NEW DEPLETION ZONE ACTS LIKE AN INSULATING AIR GAP.

14. ANY ELECTRONS WHICH RANDOMLY WANDER ALL THE WAY ACROSS THE BASE ARE GRABBED BY THE COLLECTOR; THEY'RE *FORCED*ACROSS THE UPPER DEPLETION ZONE.

15. THE BASE DEPLETION ZONE CONTROLS THE COLLECTOR BATTERY CURRENT. BUT CHANGES IN THE COLLECTOR VOLTAGE HAVE LITTLE EFFECT.

If we crank up the Base Battery voltage, the emitter's depletion layer thins, the "switch" is fully on, and a very large flow of charge might appear in the collector circuit. Uh oh. The transistor (as a switch) is trying to short out the collector battery. So lets have it switch something. Give it a light bulb in series.

```
                    ________    Light
                   /        \   Bulb
        |     ________/\/\/\________
        |    |                      |
        |    |      \________/      |
v    |                     |
            |                       |
            |               ______|______
            |              |             |
  Collector |              | COLLECTOR N |     Thick depletion
  Battery   |    +         |_____________|     layer with electrons
            |               _____________   <-- passing through
        ____|____          |             |______________
          _____            | BASE      P |              |
        _________          |=============|              |   +
          _____    9V      |             |          ____|____
        _________          | EMITTER  N  |            _____    Base
          _____            |_____________|          _________  Battery
        _________                 |                   _____     .7V
          _____                   |                     |   -
            |    -                |_____________________|
            |_____________________|

                ------>
```

And finally we take one last look at the flow of charge in the base wire. Even though it's really the *voltage* between base and emitter which controls the transistor, we don't ignore the base-wire's current entirely. It has an important use. Just by coincidence the tiny base/emitter current is proportional to the large collector/emitter current. So if we know the value of flowing charge in the base wire, we can multiply

its value by this "Current Gain" factor, and then figure out just what the charge-flow in the Collector wire should be. The transistor ACTS as if it is amplifying current. But it's really using a small change in *voltage* to create a large change in current. (It's more than just coincidence that the charge flowing in the Base and Collector are proportional. In fact, both flows are controlled by the Base/Emitter voltage, which controls the thickness of the Emitter's depletion layer.) The Collector current is large because the Emitter's thin depletion layer lets huge amounts of electrons escape up into the Collector region. The current in the Base wire is small because only a few electrons are needed in order to change the BE voltage and the thickness of the Emitter's depletion zone.

A voltage in one place controls a flow of charge in another. This fact even determines the name of the entire device. Changing a voltage causes a change in current, so the device behaves somewhat like a RESISTOR. But the voltage that controls the current is on an entirely different wire. It's as if the effects of the voltage are TRANSFERRED from the Base side of the circuit to the Collector side. Transfer resistor. Transistor.

16. BASE VOLTAGE CONTROLS COLLECTOR CURRENT.

17. PURE LUCK?: THE BASE LEAKAGE IS PROPORTIONAL TO COLLECTOR CURRENT.

18. TRANSISTORS ARE *NOT* CURRENT AMPLIFIERS. BUT IT CERTAINLY SIMPLIFIES THINGS IF WE PRETEND THAT THEY ARE.

So, was this explanation too big and nasty? It certainly would be easier if all the textbook authors themselves had a better idea of how transistors work. It would be easier if they stopped telling people that transistors "amplify current." And it certainly would be easier if I get off my butt and create some animations to illustrate the above text!

PS
The transistor was invented around 1923, by physicist Dr. J. Edgar Lilienfeld, the father of the modern electrolytic capacitor. WHAT?!!! But everyone knows that it was invented at Bell Labs in 1945. Nope. The original transistor was a 1920s thin-film device deposited on glass. The base region was a clever idea: crack a piece of glass, put it back together with metal foil clamped in the crack, then slice off the extra foil to make a flat surface that goes: glass, metal, glass. Deposit a thin layer of semiconductor and heat the device, and the thin metal line will "dope" that part of the semiconductor layer. Simple! But Dr. Lillienfeld unfortunately didn't have a solid theory to explain how his invention worked, so it was ignored. Some hobbyist should try making a home-built transistor.

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Crystal Triode Action in Lead Sulphide, P. C. Banbury, H.A. Gebbie, C. A. Hogarth, pp78-86. SEMI-CONDUCTING MATERIALS, Conference proceedings, H.K. Henisch (ed), 1951 Butterworth's scientific publications LTD 1951.

PPPS
WHAT ARE TRANSISTORS USED FOR? Ah, that's a whole 'nother article. But here's one example. Computers are made out of processors and memory. Processors are made out of "state machines" and "data selectors," while memory is made out of data selectors and the flipflops that store the individual bits. State machines in turn are are made out of data selectors, and data selectors are made out of nand-gates or nor-gates. Memory flipflops are made out of nand-gates or nor-gates. EVERYTHING is made out of Nand or Nor gates. And...nand-gates and nor-gates are made out of transistors.

So... computers are entirely made out of transistors. If computers are like animals, then animals are made of tissues, which are made of cells, which are made of organelles, which are made of proteins, which are made of molecules, which are made of atoms. Yet an animal is entirely made of atoms, and everything else is just interesting patterns in those atoms. Digital electronics has similar levels of complexity and organization, and in digital electronics, *the transistor is the "atom."* The transistor looks too simple though. It looks uninteresting. Ah, but when you have clusters of transistors hooked together in various ways, THEN you'll learn all the fascinating things you can do with them.

PPPPPPPS
People often ask: is a transistor an amplifier, or is it some sort of valve? The answer is

yes. The answer is yes because all valves are amplifiers. How much energy does it take to open a faucet? Now think about the large amount of work the flowing water can perform. A nicely made faucet could be opened and closed with one finger, but connect the output to a water turbine, and it can do work at a rate of many horsepower. The energy of your finger motion is multiplied by tens of thousands of times. Yet it's the distant power supply; the city water pumps, which actually do the work. Transistors behave in much the same way. Connect a transistor to a power supply, and you've got a crude amplifier.

PPPPPPPPPPPS

This article apparently has triggered extensive debates if not flamewars on multiple hobbyist forums, newsgroups, and WP. It's as if many people see Ic=hfe*Ib as holy, while Ic=Is(e^Vbe/Vt) is dark blasphemy which must be kept from the delicate ears of children. The cause of controversy is fairly obvious: at early stages we're all taught that BJTs are current-controlled devices, and only in later engineering physics courses is this claim held up to questioning. Also, the current-control viewpoint works just fine as long as we give it lip service and then turn around and use Spice programs, or as long as we never look too closely at details of the inner workings of the physics. This situation leads most people to firmly decide that Ic really is affected by Ib and not by Vbe. (Or perhaps they believe that, in diodes, the Vf diode drop is caused by the current.) I note that these debates all seem to feature typical flaws:

1. Primary is a sort of backwards reasoning: first we take a stance for (or against) current control. Then we hotly defend that stance against all comers while cherry-picking the supporting evidence and ridiculing all contrary evidence. But that's not reason. That's religion or politics. It's how pseudoscientists operate. Science is the very opposite: in science, first we try like hell to avoid rigid preconceptions and emotional biases. We take no stand for or against. Then we honestly ask which side is actually right: ask whether transistors are controlled by voltage or by current. And then we take the answers seriously, without desperately twisting facts to avoid losing face in public, without breaking sweat while having steam shoot out our ears, and without descending into mild insanity triggered by psychological denial that we're genuinely on the 'losing' side. :)

2. Second problem: is the BJT current-control viewpoint *really* held by all scientists and engineers everywhere, while voltage control is terribly wrong? WRONG. :) Look at the Ebers-Moll section of Sedra/Smith, Horowitz/Hill, or most any engineering text. Ask some engineering authors (many are online!) Ask semiconductor physicists. Ask professional engineers. Their answers will surprise you. (And don't ask them about abstract models of black-box transistors, ask about the topic of my article: the internal physics: whether Vbe determines Ic, what is the origin of the Shockley equation, and what role does Ib play in determining Ic?)

3. Third problem: transient Ib current causes confusion. When Vbe changes value, charges must move during the changing profile of the depletion layer, and this requires a momentary charge flow in the base lead. I've seen several people proclaiming that this proves that Ib "causes" Vbe. No, that's a clear attempt to twist facts. The voltage across a capacitor sitting on a shelf isn't being "caused" by any continuing current. In truth it just means that a *changing* capacitor voltage always requires a momentary current. To explain the high frequency behavior, you need Gummel-Poon and not just Ebers-Moll. This issue doesn't apply to the low-freq or DC case of Ic=Is(e^Vbe/Vt) where Vbe is constant, yet the values of Vbe, Ic, and Ib are all connected together. The Ebers-Moll model shows that Ic is proportional to Vbe, but in order to see this, we must ignore the Emitter-Base capacitance and the transient currents which charge or discharge the EB capacitor during changing conditions.

4. Fourth problem: we've all been taught that BJT transistors are totally different than FET transistors. After all, BJTs are bipolar, requiring both electrons and "holes." Well, this is wrong. There, I've said it. (Next flamewar can start now!) Schockley didn't know what he was talking about at the time. Today it's too big of an error to try correcting, or even to face. Schottky diodes, where metal and N-type doping cause rectification without holes, came later. It's possible to make a BJT transistor which uses no holes. This highlights the central difference between FETs and BJTs: in FETs the insulating regions invade from the side and make the conductive path narrower. In BJTs the insulating region is always cutting across the conductive path, but it can be made so thin that it cannot block even an immense charge flow. If a FET is like an electricity shutter, then a BJT is like "electricity sunglasses" where you can alter the opacity. Aaaaaand... you don't need any holes to form a depletion layer. The holes aren't part of the requirements. BJTs don't need the "B," just the "JT." (Now just try to imagine a huge community like EEs and Techs trying to admit the mistake, and attempting to go back and change the name of the Bipolar Junction Transistor! Ain'tgonna happen.)

5. Fifth problem: down inside any resistor, the current density is controlled by the value of e-field, but the e-field isn't determined by the current density. Huh? Try again: charges get accelerated by electrostatic fields, but the reverse is not true: an accelerating charge is not the cause of that e-field. And ...at the macroscopic level, this means that voltage causes current. Voltage always causes current. Current cannot cause voltage.

   Whaaaaat? Before you get in a lather, make note of the following. Yes, if we already know the values of the current and resistance, we can work backwards and calculate the voltage which was causing the current. Current can reveal the value of an unknown voltage, if resistance is known. But the resistor itself

doesn't work backwards: the e-field accelerates the mobile charges, and not the reverse. (Similarly, a gravitational potential pulls a dropped rock downwards, but if you manually accelerate a rock towards a surface, this doesn't create a gravity potential.) And so in diodes, Vf determines the diode current, but the current doesn't cause Vf. Yet isn't all of this crazy talk, because Ohm's law works fine when we assume that *current causes voltage.* Yes, that's right, and it's because Ohm's law ignores the internal physics. Ohm's law is a simplified abstract model, and a very useful one. It treats a resistor as a black box. But Ohm's law is "wrong" in that it incorrectly implies forward and reverse causation between e-fields and carrier drift. As a mental model, "current causes voltage" is incredibly useful. But if we believe that this mental model is *actually true,* it's a classic error called "reification." See where I'm going with this? The belief that BJTs are current controlled devices is a good example of the Reification Fallacy: a belief that a simplified abstract concept; a mathematical model, has real-world concrete existence.

Reification (fallacy)

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This article **needs additional citations for verification.**
Please help improve this article by adding reliable references. Unsourced material may be challenged and removed. *(August 2010)*

Reification (also known as **hypostatisation**, **concretism**, or **the fallacy of misplaced concreteness**) is a fallacy of ambiguity, when an abstraction (abstract belief or hypothetical construct) is treated as if it were a concrete, real event, or physical entity.[1][2] In other words, it is the error of treating as a "real thing" something which is not a real thing, but merely an idea. For example: if the phrase "holds another's affection", is taken literally, *affection* would be reified.

Another common manifestation is the confusion of a model with reality. Mathematical or simulation models may help understand a system or situation but real life always differs from the model. In extreme cases, the butterfly effect causes the model to rapidly diverge from what is occurring in real life.

Note that reification is generally accepted in literature and other forms of discourse where reified abstractions are understood to be intended metaphorically,[2] but the use of reification in logical arguments is usually regarded as a fallacy. For example, "Justice is blind; the blind cannot read printed laws; therefore, to print laws cannot serve justice." In rhetoric, it may be sometimes difficult to determine if reification was used correctly or incorrectly.

[edit] Etymology

From Latin*res* thing + *facere* to make, reification can be 'translated' as thing-making; the turning of something abstract into a concrete thing or object.

[edit] Theory

Reification often takes place when natural or social processes are misunderstood and/or simplified; for example when human creations are described as “facts of nature, results of cosmic laws, or manifestations of divine will”.[3] Reification can also occur when a word with a normal usage is given an invalid usage, with mental constructs or concepts referred to as live beings. When human-like qualities are attributed as well, it is a special case of reification, known as pathetic fallacy (or anthropomorphic fallacy).

Reification may derive from an inborn tendency to simplify experience by assuming constancy as much as possible.[4]

[edit] Difference between reification and hypostatisation

Sometimes a distinction is drawn between reification and hypostatization based on the kinds of abstractions involved. In reification they are usually philosophical or ideological, such as existence, good, and justice.[2]

[edit] Fallacy of misplaced concreteness

In the philosophy of Alfred North Whitehead, one commits the **fallacy of misplaced concreteness** when one mistakes an abstract belief, opinion or concept about the way things are for a physical or "concrete" reality.

There is an error; but it is merely the accidental error of mistaking the abstract for the concrete. It is an example of what I will call the ‘Fallacy of Misplaced Concreteness.’[5]

Whitehead proposed the fallacy in a discussion of the relation of spatial and temporal location of objects. Whitehead rejects the notion that a concrete physical object in the universe can be ascribed a simple spatial or temporal extension, that is, without reference of its relations to other spatial or temporal extensions.

...among the primary elements of nature as apprehended in our immediate experience, there is no element whatever which possesses this character of simple location. ... [Instead,] I hold that by a process of constructive abstraction we can arrive at abstractions which are the simply located bits of material, and at other abstractions which are the minds included in the scientific scheme. Accordingly, the real error is an example of what I have termed: The Fallacy of Misplaced Concreteness.[6]

[edit] Similar fallacies

Pathetic fallacy (also known as anthropomorphic fallacy or anthropomorphization) is a specific type of reification. Just as reification is the attribution of concrete characteristics to an abstract idea, a pathetic fallacy is when those characteristics are specifically human characteristics, thoughts, and feelings.[7] Pathetic fallacy is also related to personification, which is a direct and explicit in the ascription of life and sentience to the thing in question, whereas the pathetic fallacy is much broader and more allusive.

The animistic fallacy involves attributing intention of a person to an event or situation. This is usually not reification because the "real" attributes are given to the perceived person involved, and not the event or situation. For example, "The train's conductor must have been impatient, so we missed the train." (animistic fallacy), compared to "The train was impatient." (reification).

Reification fallacy should not be confused with other fallacies of ambiguity:

- Accentus, where the ambiguity arises from the emphasis (accent) placed on a word or phrase
- Amphiboly, a verbal fallacy arising from ambiguity in the grammatical structure of a sentence
- Composition, when one assumes that a whole has a property solely because its various parts have that property
- Division, when one assumes that various parts have a property solely because the whole has that same property
- Equivocation, the misleading use of a word with more than one meaning

[edit] As a rhetorical device

Reification is commonly found in rhetorical devices such as metaphor and personification. In those cases we are usually not dealing with a fallacy but with rhetorical applications of language. The distinction is that the fallacy occur during an argument that result in false conclusions. This distinction is often difficult to detect, particularly when the fallacious use is intentional.[2]

[edit] See also

- Buddhist philosophy
- Map–territory relation
- No true Scotsman
- Philosophical realism
- Vitalism

[edit] References

1. ^List of common fallacies: Reification
2. ^ abcdLogical Fallacies, Formal and Informal
3. ^ David K. Naugle, *Worldview: the history of a concept*, Wm. B. Eerdmans Publishing, 2002, ISBN 0802847617, Google Print, p.178
4. ^ David Galin in B. Alan Wallace, editor, *Buddhism & Science: Breaking New Ground.* Columbia University Press, 2003, page 132.

5. ^Whitehead, Alfred North (1997) [1925]. *Science and the Modern World*. Free Press (Simon & Schuster). p. 51. ISBN 0684836394.
6. ^Whitehead, Alfred North (1925) [1919]. *An Enquiry concerning the Principles of Natural Knowledge* (2nd ed.). Cambridge University Press..
7. ^Reification fallacy as used in agnosticism and atheism discussions

[hide]v·d·e**Informal fallacies**

Absence paradox ·Begging the question ·Blind men and an elephant ·Cherry picking ·Complex question ·False analogy ·Fallacy of distribution (Composition ·Division) ·Furtive fallacy ·Hasty generalization ·I'm entitled to my opinion ·Many questions (Loaded question) ·McNamara fallacy ·Name calling ·Red herring fallacy ·Special pleading ·Rationalization (making excuses) ·Slothful induction

Correlative-based fallacies	False dilemma (Perfect solution) ·Denying the correlative ·Suppressed correlative
Deductive fallacies	Accident ·Converse accident
Inductive fallacies	Sampling bias ·Conjunction fallacy ·False analogy ·Hasty generalization ·Misleading vividness ·Overwhelming exception
Vagueness and ambiguity	Amphibology ·Continuum fallacy ·False precision ·Slippery slope
Equivocation	Equivocation ·False attribution ·Fallacy of quoting out of context ·Loki's Wager ·No true Scotsman ·**Reification**
Questionable cause	Animistic ·Appeal to consequences ·Argumentum ad baculum ·Circular cause and consequence ·Correlation does not imply causation (Cum hoc) ·Gambler's fallacy and its inverse ·Post hoc ·Prescience ·Regression ·Single cause ·Slippery slope ·Texas sharpshooter ·The Great Magnet ·Unknown Root ·Wrong direction

List of fallacies ·Other types of fallacy

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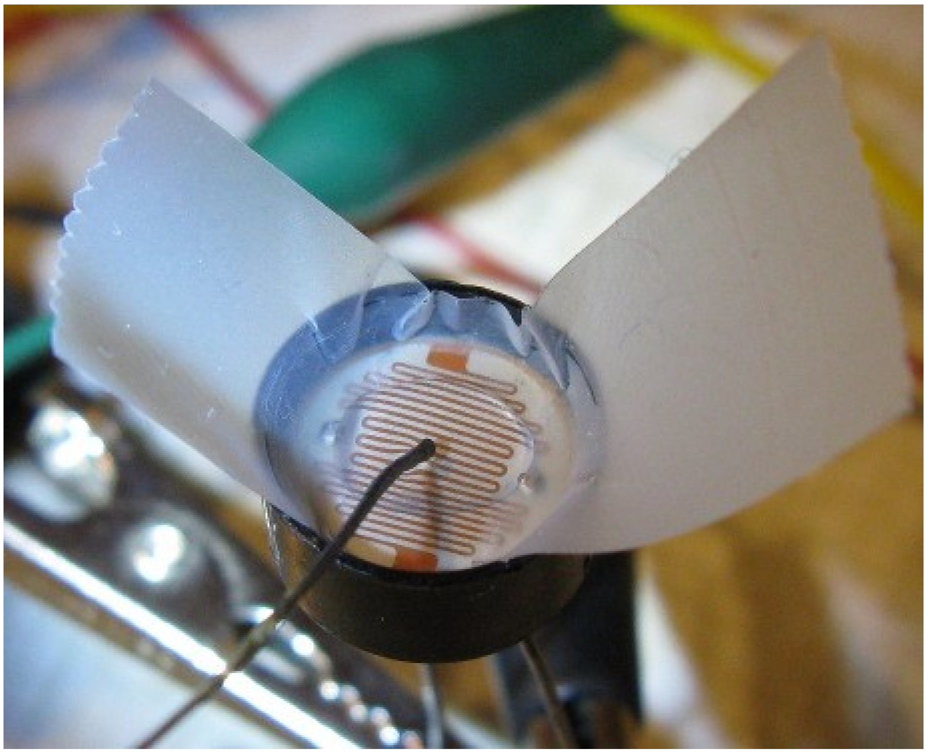
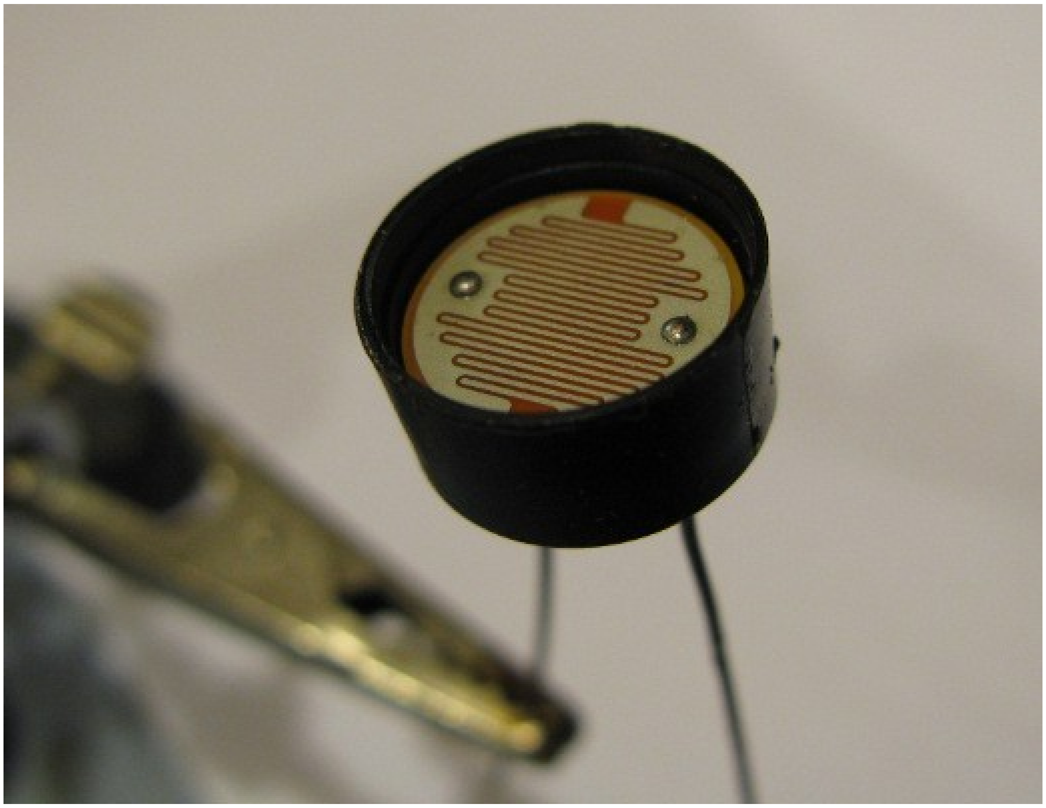
By Nyle Steiner K7NS May 7 2009.

Updated May 10 2009

CDS Photocell Made Into A FET Transistor



The picture above shows how transistor action was observed by improvising an insulated gate to a cadmium sulfide photo resistor. The picture was taken in normal light but the experiment had to be performed in the dark.



The photocell used is pictured above. It is a very common type which I purchased from Radio Shack many years ago.

Photo Resistor Converted Into A Field Effect Transistor.

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It recently occurred to me that if this is the case, I might be able to create transistor action through a cadmium sulfide photocell (actually a photo sensitive resistor) since they consist of basically a thin semiconductor film between two electrodes. This simple experiment would be a logical first step before trying to create my own thin semiconductor films. Would this photocell act as a transistor if I put an insulated gate near it?

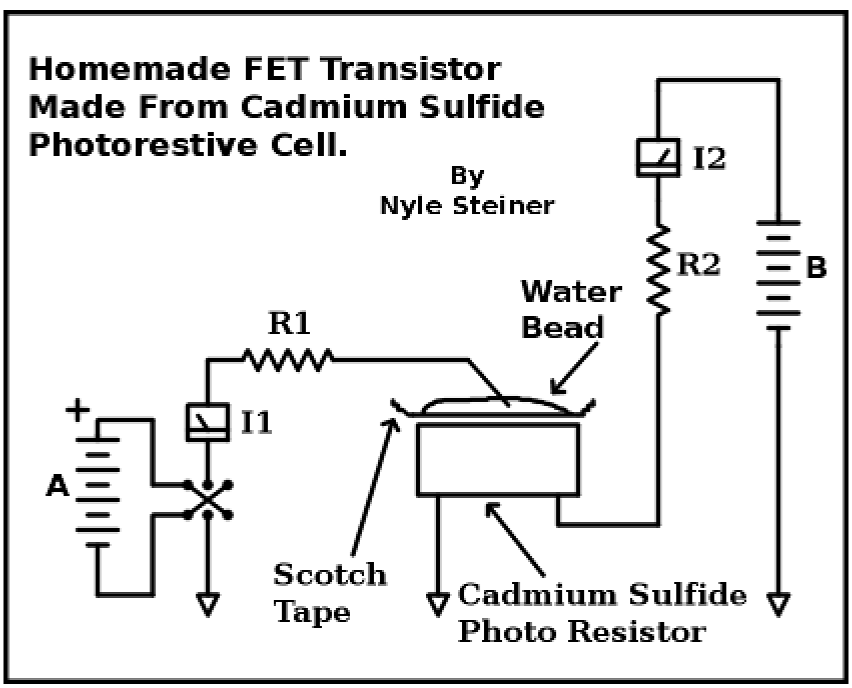
My first attempt was simply to observe if there is any current change through the photocell while moving a charged comb or pvc pipe near it. The excitement of seeing the current change was short lived after realizing that the light striking the photocell was also affected by the moving comb. I needed some light in the room to watch the meter. Several years ago

I had also tried moving a charged comb near some catwhisker devices to see if the current changed. Seeing some current change at that time, was exciting until I realized that the electrostatic attraction from the charged comb was physically pulling on the catwhisker. I have long wondered if simply putting a charged object near a semiconductor or other type of film, could have an effect on electrical current flowing through the film. For now, that question still remains unanswered.

It was time to try improvising some kind of conductive gate near the surface of the photocell. I did this by putting a piece of scotch tape across the face of the photocell to act as the insulator. To make a conductive layer in close contact, I then put a drop of water on top of the scotch tape just big enough to cover most of the photocell area. I used water because of it's ability to conform closely to the surface of the tape. Nothing needed to be added to the water because the resistance of normal water is very low compared to the almost infinite resistance of this improvised gate. A piece of wire touching the drop of water served as the gate electrode.

From my observations, the setup described above definitely produces transistor action. This experiment had to be performed in the dark for obvious reasons although I found that a tiny bit of light falling on the photocell could sometimes improve performance. There was little or no transistor action in normal light because the photocell was saturated.

This transistor has considerable power gain but very low voltage gain because of the wide voltage excursions required at the gate to produce a significant current change through the photocell. Intuition says the gate could be made more sensitive by putting the gate closer but the thickness of the scotch tape and the clear coating on the front of the photocell precluded this. The gate input resistance is for most practical purposes, infinite. The only current that flows through the gate is whatever current can leak through a piece of scotch tape.



Battery B supplies current through the photocell and R2. Current through the photocell is measured by I2. Battery B was varied between 9 VDC to 175 VDC.

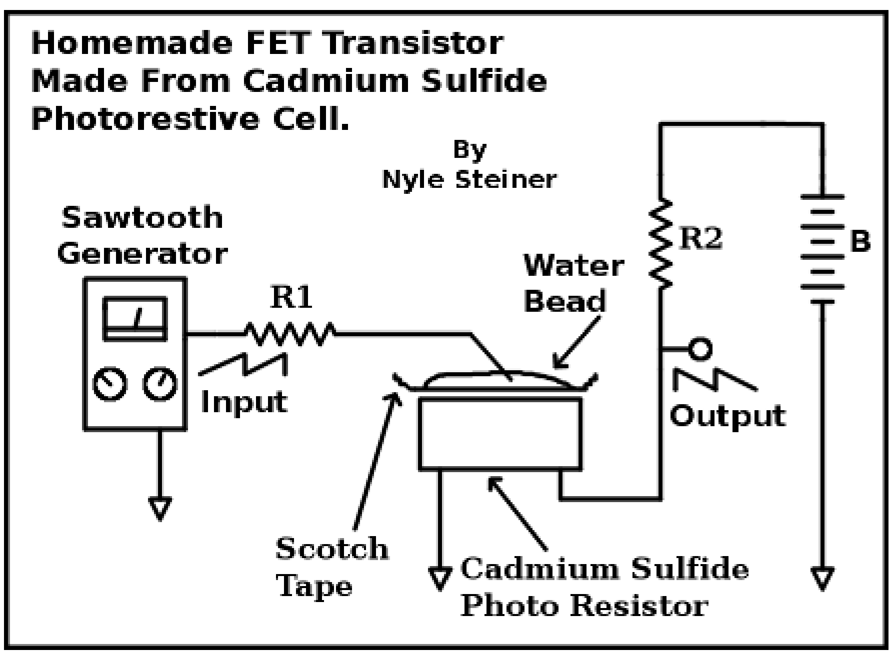
Battery A was varied between 75 VDC and 175 VDC and was connected through a switch to be able to reverse the polarity of voltage applied to the gate.

Whenever the switch was changed, the polarity of voltage across the gate would reverse, resulting in a current change through I2.

R1 and R2 were used mainly to limit current and protect the current meters in case of a high current. Since the gate impedance is so high, R1 could be anywhere between zero and 10 meg without noticing any significant difference.

This device acted as an enhancement-depletion insulated gate FET. A positive voltage applied to the gate caused an increase of current through I2 and a negative voltage applied to the gate caused a decrease in current through I2.

The gate, being such high impedance, is what makes the power gain of this device so high. A change of even several hundred volts across the gate usually causes at most a small fraction of a microamp - barely perceptible needle movement on a 50 ua full scale ammeter I1. This translates into a very small change of power dissipated in the gate circuit. This voltage change on the gate can cause many microamps of current change through the photocell. That translates into a significant change of power dissipated in the output circuit across R2.



The response of this device also seemed to have a dynamic characteristic. That is, whenever the reversing switch was activated, the current through R2 would suddenly change and then slowly creep back toward the previous value. By running a sawtooth waveform into

the gate however, I was able to establish to my satisfaction, that indeed the output current was responding to the input voltage.

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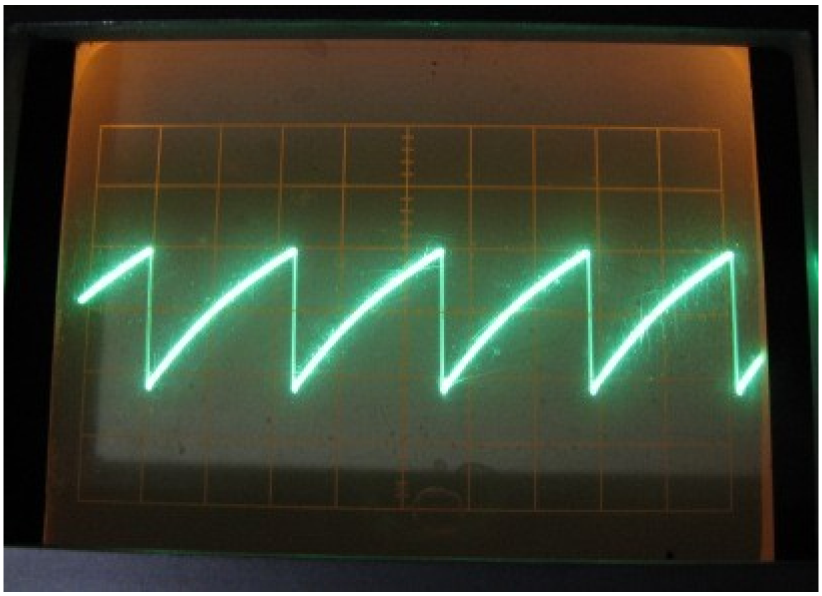
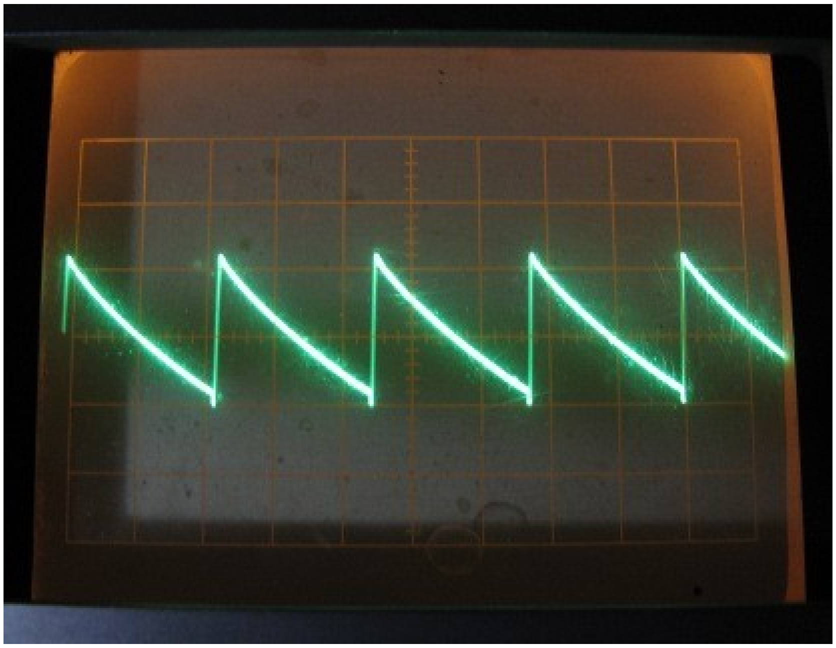
Input Sawtooth Waveform



Output Is Inverted Sawtooth Waveform



The tiny spike at the bottom of the waveform is a small amount of input signal feeding directly to the output through stray capacitance.

Homemade FET Transistor Used To Make A Power Amplifier.

Meter readings and oscilloscope signals are great for evaluating devices such as this homemade transistor but, evaluation would not be complete without building an actual amplifier circuit and attempting to hear an amplified signal. I was successful at doing that.

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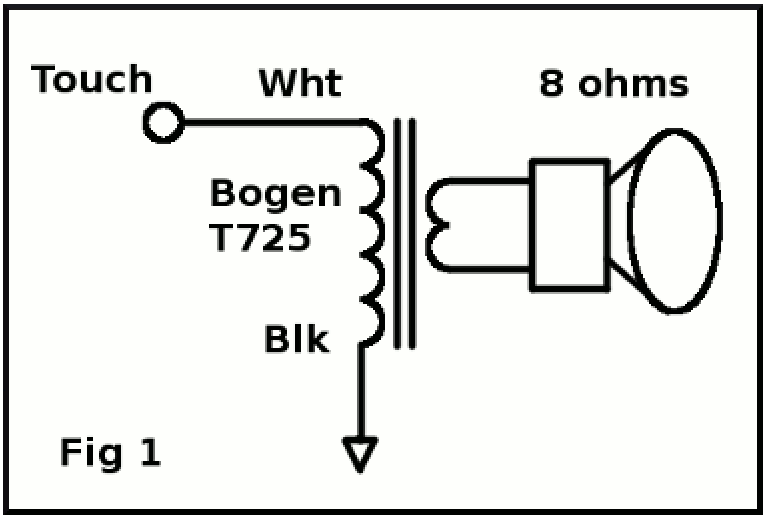

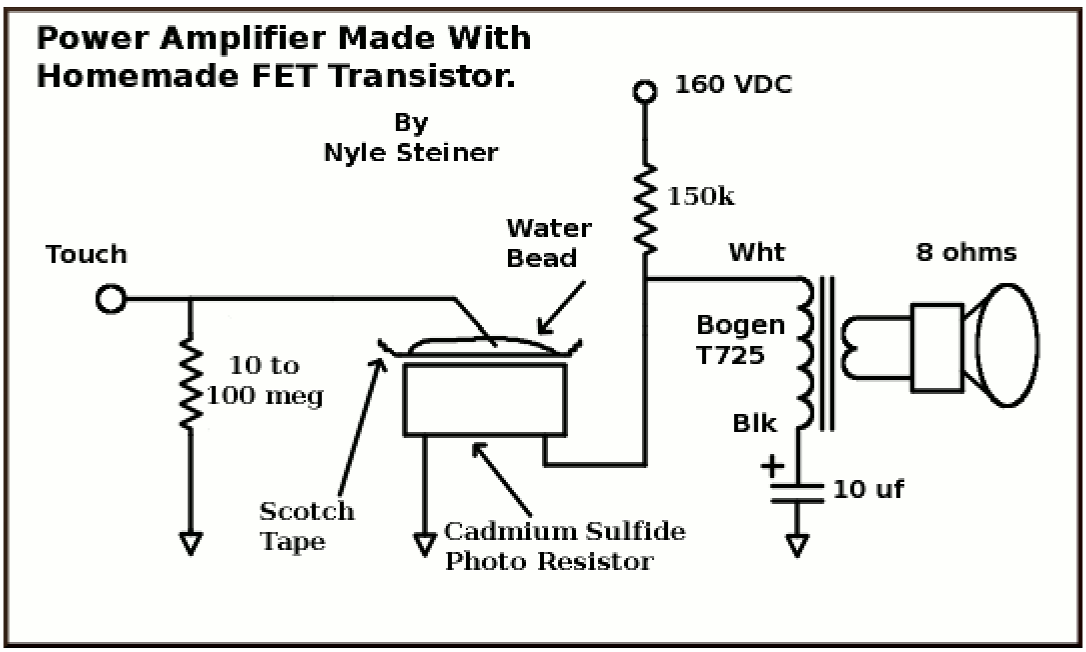

The homemade transistor requires a slight amount of light for optimum operation.

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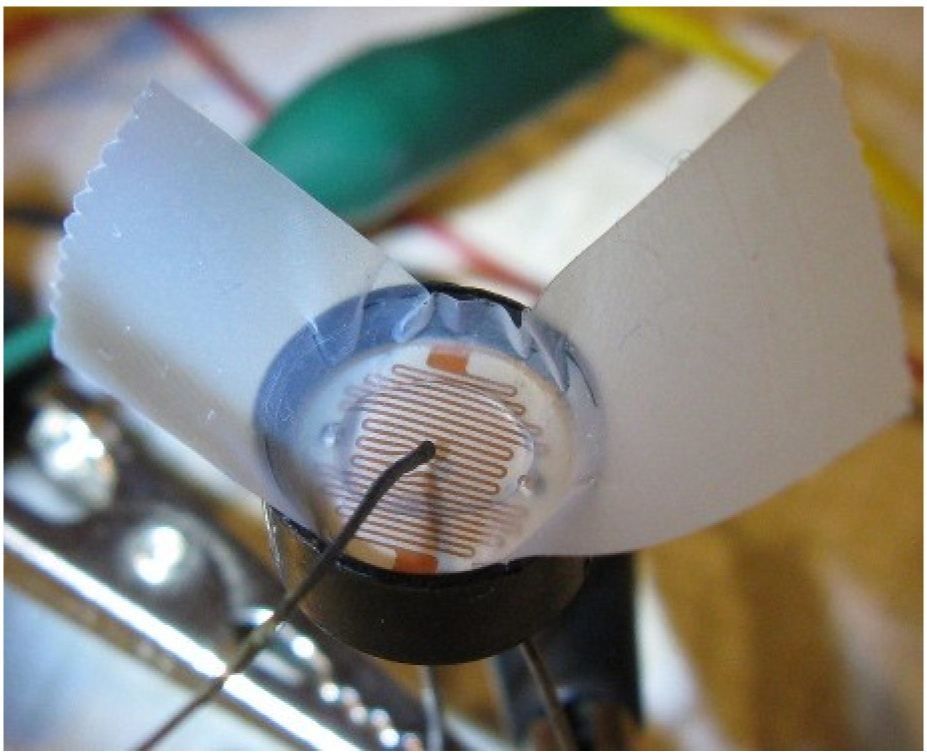

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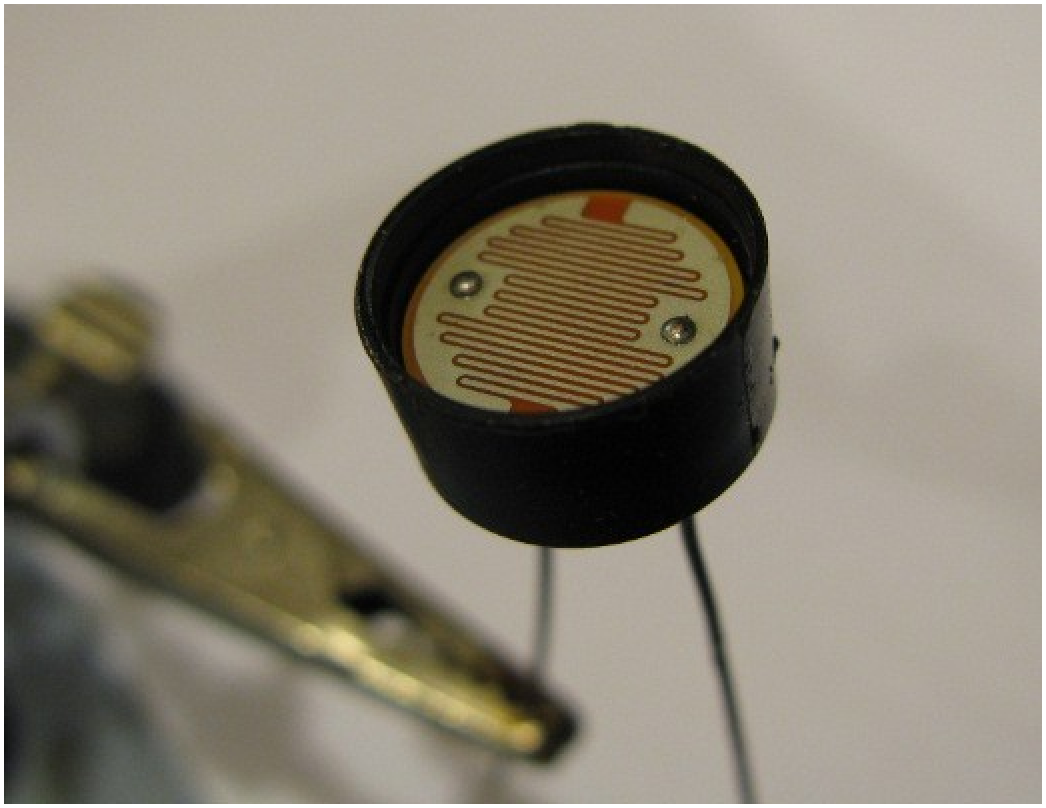

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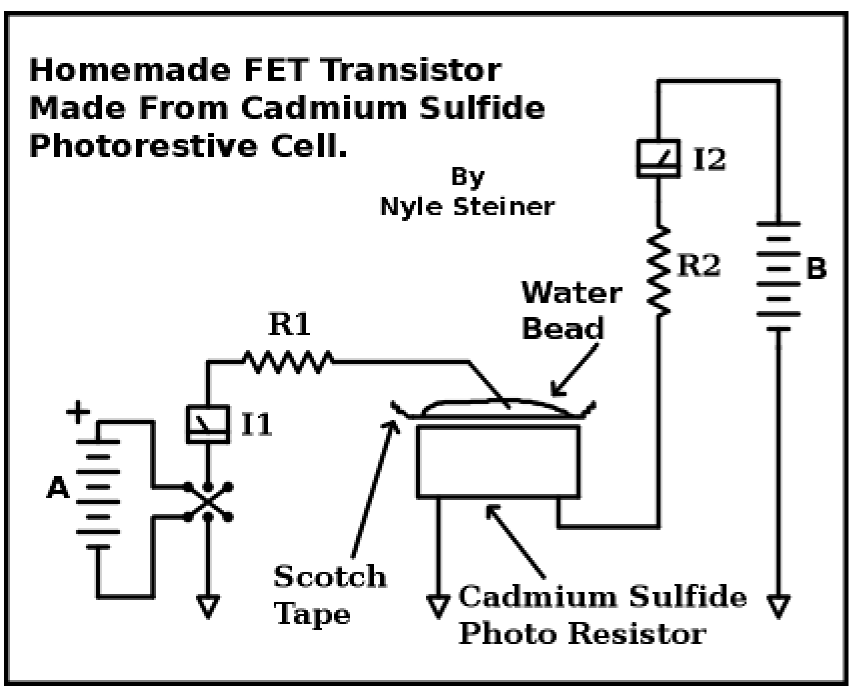

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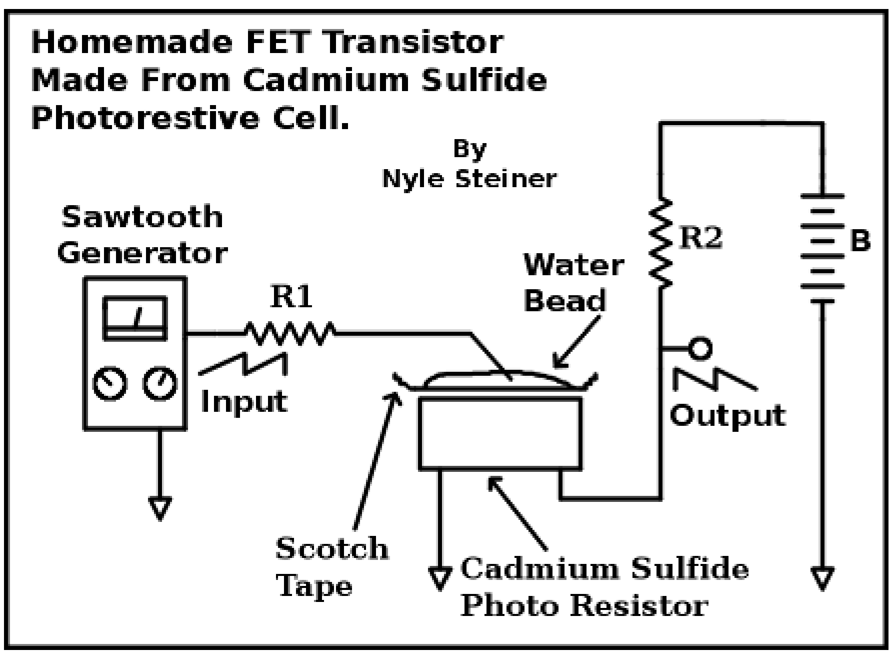

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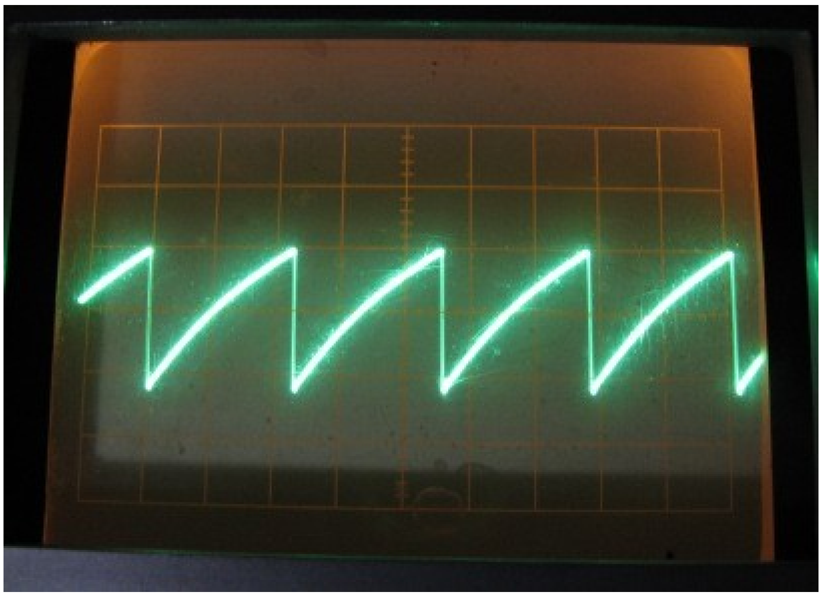

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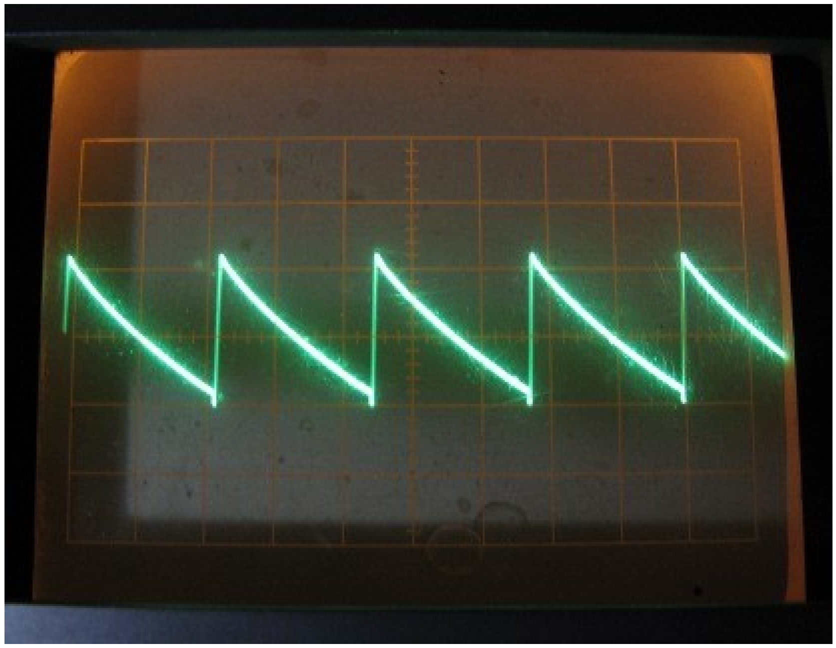

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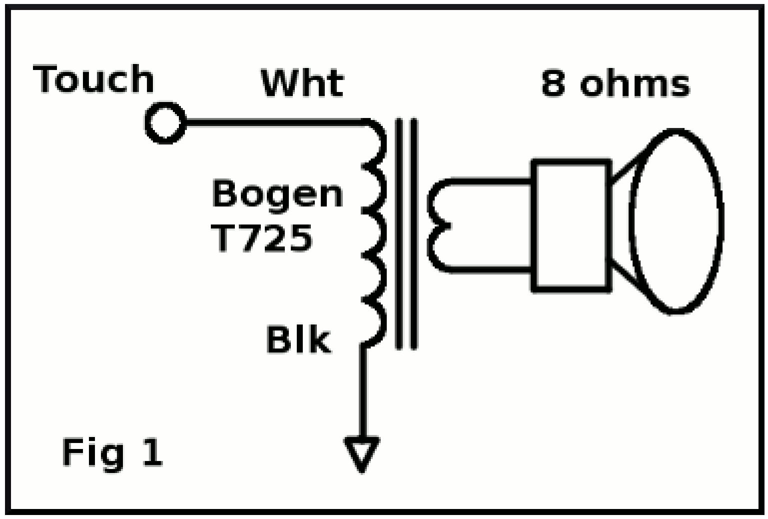

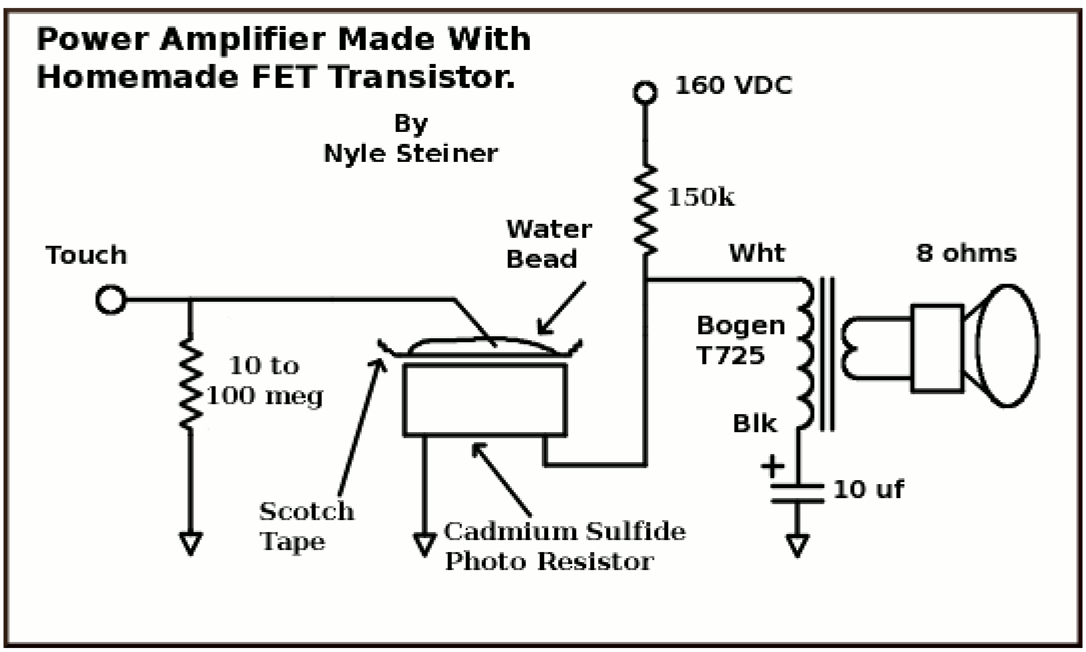

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CAPACITOR COMPLAINTS

1996 William J. Beaty

```
Date: Sat, 8 Jun 1996 14:17:53 -0700 (PDT)
From: "Bill Beaty"
To: ELECTRON@CCTR.UMKC.EDU
Subject: Re: light bulbs

On Thu, 6 Jun 1996, Rader William E wrote:
>  On a more serious note (for every one out there), I would like to
> know how a capacitor REALLY works. I have read as many texts as you have
>but don't you believe them !
> If you have access to a high voltage generator (Wimherstsic ) and a
>take-apartableLayden jar please play(i mean experiment) with these and
> tell me how a capaciator really works
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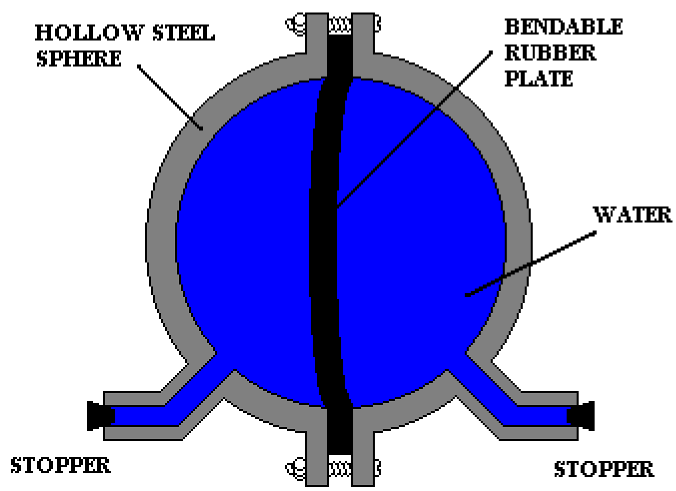
I have beefs with textbook explanations of capacitors too. "Capacitors store charge." No! Flat out wrong! Wait and hear me out, I'm not insane.

;)



CAPACITOR
(water analogy)

When we "charge" a conventional metal-plate capacitor, the power supply pushes electrons into one plate, and the fields from these extra electrons reach across the gap between the plates, forcing an equal number of electrons to flow out of the other plate and into the power supply. This creates opposite areas of imbalanced charge: one plate has less electrons and excess protons, and the other plate has more electrons than protons. Each plate does store charge.

However, if we consider the capacitor as a whole, no electrons have been put into the capacitor. None have been removed. The same number of electrons are in a "charged" capacitor as in a capacitor which has been totally "discharged." Yes, a certain amount of charge has been forced to flow momentarily during "charging," and a rising potential difference has appeared. But the current is directed THROUGH the capacitor, and the incoming electrons force other electrons to leave at the same time. Every bit of charge that's injected into one terminal must be forced out of the other terminal at the same time. The amount of charge inside the capacitor never changes. The net charge on each plate is cancelled by the opposite charge on the other plate. Capacitors are never "charged" with electric charge!

Think about this:

When "charging" a capacitor, a momentary current causes the voltage to rise. Volts times electron-flow equals energy-flow (V x I = P). Therefore during a momentary current through a capacitor, there is a joules-per-second transfer of energy from the power supply into the capacitor.

Therefore, during the "charging" process, ENERGY is placed in the capacitor. Capacitors store energy, not charge. When we "charge" a capacitor, we give it a charge of energy. Because we use the word "charge" to refer both to electric charges and ALSO to quantities of energy, capacitor explanations are impossible to understand. "Charging" a capacitor means injecting electrical energy into the device.

Similar trouble is caused when we say that we "charge" a battery. We charge a battery with some energy in the form of stored chemical fuel, but we pump electric charge THROUGH the battery and none of it builds up inside.

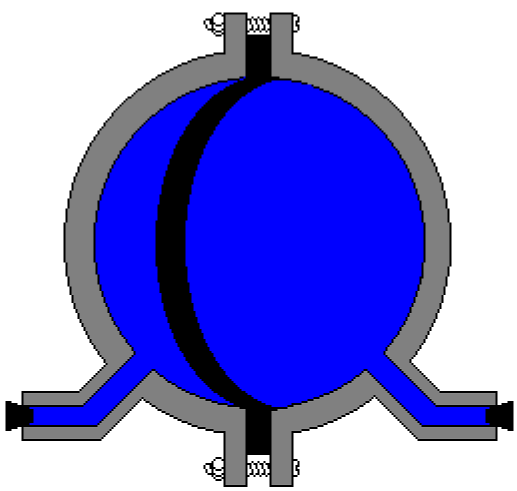
It's all terribly confusing. What are students to think if we tell them that "charging a battery" does not store any charge, yet charge must flow through the battery if we want to charge it! Ugh. The word "charge" has far too many meanings. In science this is always a **Very Bad Thing.**

Another, less misleading situation is similar: think of the word "charge" as applied to gunpowder. A charge is placed in an old cannon, followed by a cannonball. It would be silly to assume that, because we've "charged" the cannon, the cannon now has an electrical charge. But whenever we state that we've "charged" a capacitor, we DO assume that an electrical charge has been stored inside. This is just as silly as mistaking gunpowder for electrostatic charges. Charging a capacitor is like charging a cannon; in both situations we are inserting energy, not electrical charge.

Here's yet another way to visualize it. Whenever we "charge" a capacitor, the path for current is THROUGH the capacitor and back out again. The extra electrons on one plate force electrons to leave the other plate, and vice versa. Visualize a capacitor as being like a belt-driven wind-up motor. If we shove the rubber belt along, the spring-motor inside the capacitor winds up. If next we let the rubber belt go free, the wound-up spring inside the motor drives the belt in the other direction, and the spring becomes "discharged." But no quantity of "belt" is stored inside this motor. The belt flows THROUGHT it, and we wouldn't want to label this motor as a "machine which accumulates rubber." Yet this is exactly what we say whenever we state that a capacitor "stores charge."

My favorite capacitor analogy is a heavy hollow iron sphere which is completely full of water and is divided in half with a flexible rubber plate through its middle. Hoses are connected to the two halves of the sphere, where they act as connecting wires. The rubber plate is an analogy for the dielectric. The two regions of water symbolize the capacitor plates.

Imagine that the rubber plate is flat and undistorted at the start. If I connect a pump to the two hoses and turn it on for a moment, the pump will pull water from one half of the iron sphere and force it into the other. This will bend the rubber divider plate more and more. The more the plate bends, the higher the back-pressure the plate exerts, and finally the pressure will grow strong enough that the pump will stall. Next I seal off the hose connections and remove the pump. I now have created a "charged" hydraulic capacitor.



HIGHLY "WATERED" CAPACITOR

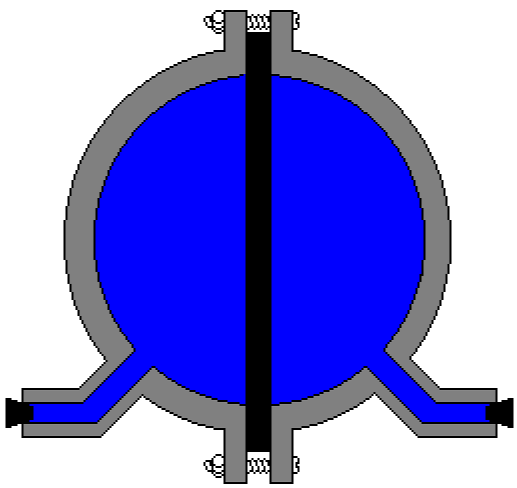
(IT CONTAINS FAR MORE WATER THAN BEFORE. NO?)

Now think: in this analogy, water corresponds to electric charge. How much water have I put into my iron sphere? None! The sphere started out full, and for every bit of water that I took out of one side, I put an equal amount into the other. When the pump

pushed water into one side, this extra water also forced some water out of the other side. No water passed through the rubber. Even so, essentially I drove a water current THROUGH my hydraulic capacitor, and this current pushed on the rubber plate and bent it sideways. Where is the energy stored? Not in the water, but in the potential energy of the stretched rubber plate. The rubber plate is an analogy to the electrostatic field in the dielectric of a real capacitor.

It would be misleading to say "this iron sphere is a device for accumulating water", or "this sphere can be charged with water, and the stored water can be retrieved during discharge." Both statements are wrong. No water was injected into the sphere while it was being "charged."

Imagine that I now connect a single length of pre-filled hose between the two halves of the capacitor. As soon as the last connection is complete, the forces created by the bent rubber plate will drive a sudden immense spurt of water through this hose. Water from one side will be pushed into the other side, and the rubber plate will relax. I've discharged my hydraulic capacitor. How much water has been discharged? None! A momentary current has flowed through the sphere device, and the rubber plate is back to the middle again, and the water has become a bit warm through friction against the surfaces of the hose. The stored energy has been "discharged," but no water has escaped. The hydraulic capacitor has lost its energy, but still has the same amount of water.



COMPLETELY "DISWATERED" CAPACITOR

(IT CONTAINS NO WATER AT ALL. RIGHT?)

I never really understood capacitors until I started trying to construct proper water-analogies for them. I then discovered that my electronics and physics classes had sent me down a dead-end path with their garbage about "capacitors store electric charge." Since my discovery, I've gained significantly more expertise in circuit design, which leads me to a sad thought. Maybe the more skilled of electrical engineers and

scientists gain their extreme expertise NOT through classroom learning. Instead they gain expertise in spite of classroom learning. Maybe the experts are experts because they have fought free of their classroom learning, while the rest of us are still living under the yoke of the many electricity misconceptions we were taught.

[Hey, M. Steinberg's C.A.S.T.L.E. electricity curriculum uses the same analogy! In section 3.9, students construct a 2-chambered air capacitor with a balloon membrane stretched between the chambers. To "charge" it we take air from one side and pump it into the other.]

On Wimshurst machines and capacitors:

Do you believe that the energy in a capacitor is trapped permanently in the dielectric? Many people do. Their belief is caused by a famously misleading experiment called "Dissectable Leyden Jar." It's an experiment which involves high voltage and corona discharge. The effect it purports to prove does not occur in capacitors at lower voltages.

First charge up a Leyden jar using a Wimshurst Machine (or other source of high voltage.) Now, carefully remove the inner metal from the jar. Now remove the outer metal. Discharge everything, then hand the parts around the classroom. Next, put the parts together again, connect the two metal cylinders, and BANG!, there is a loud discharge.

Doesn't this prove that the energy in a capacitor is stored in the dielectric? No.

Whenever you take apart a Leyden jar or other high voltage capacitor, there is a corona effect which makes very strange things occur. When you electrify a Leyden jar, and then you pull the inner metal cylinder out of the jar, the capacitance value drops, and this makes the potential difference skyrocket to enormous levels. The potential tries to become huge but it cannot, because instead it creates corona along the metal edges, and and it leaks the excess charge into the air. This corona allows the opposite electrical charges to "paint" themselves onto both sides of the dielectric "jar" surface. So, if you pull a leyden jar apart, the sharp edges of the metal plates sweep along and transfer a large percentage of the separated charges from the metal plates to the glass surfaces. The energy is still there! It's still stored as a field in the dielectric,

but those separated charges are not on the mental plates anymore. Instead they are now TRAPPED ON THE GLASS SURFACE! Strange idea, huh? A capacitor with no plates, just a dielectric.

Now reassemble the Leyden jar: momentarily touch each metal plate to ground, and put it back together again. You'll find that it's still strongly electrified! The trapped charges on the glass surface can still induce equal charges on the adjacent metal plates. Touch the two terminals with your fingers and BOOM!, the momentary current in your muscles will throw you across the room.

This strange effect leads many people to claim that the energy in a capacitor is permanently trapped in the dielectric, and that it is not stored in the electric field. This is wrong.

In order to properly perform the take-apart capacitor experiment, you must execute the entire demonstration inside a big tank full of oil. This prevents the corona discharges from spewing charges from the edges of the plate onto the dielectric.

Or, perform the whole experiment at 1.0 volts, not at 10,000 volts. (Use an electrometer to measure the voltage.) You'll find that the dielectric doesn't store energy anymore. In order for the charges to spray onto the dielectric, the voltage must be high.

Or, use high voltage but do this instead: before doing anything, take apart the leyden jar. Now, lay the metal parts on a plastic sheet and use a Wimshurst machine to charge them up. Next, use plastic tongs to assemble the leyden jar. (The voltage across the plates will be very low.) NOW perform the leyden jar dissection. It shouldn't work anymore, since the initial voltage is low enough that it will prevent corona discharges from painting any charges on the dielectric.

Capacitors: physicists vs. engineers

```
> For the charge to flow in a circuit, there has to be a closed path.
> Right, sir! Please correct me if I am wrong.
```

No, there must be a closed path ONLY if the charges must flow continously in the circuit forever (pure DC). But if the charges flow briefly, or if they flow back and forth (AC), then an open path is sometimes acceptable.

For example, with a metal rod 1 meter in length, it is possible to create a standing wave of charges oscillating lengthwise in the rod with frequency 150MHz. Inside the rod, the charges move back and forth (this resembles the motions of the compressible air inside one pipe of a church organ.) The charges within the rod are acting like a compressible fluid.

At far lower frequencies, the electric current can still be large if the ends of an open circuit are joined to the plates of a capacitor. On the metal surfaces between the plates of the capacitor, the quantities of charge carriers behave as a "compressible fluid", while the charges within a wire behave as an "incompressible fluid."

```
> In the capacitor, the charge flows from one plate to the other. Let's
> assume that air is the dielectric between the 2 plates of the capacitor.
> So, there is no physical conducting path between the 2 plates. So,
>it's like an open circuit. How can we say that the charges move from
>one plate to the other?
```

Two ideas are necessary:

1. Metals are always full of movable charges even when they are electrically neutral. They contain a "fluid" made of electrons, and a "solid" made of protons (made of the nuclei of metal atoms.)

2. Negative charge can repel the "hidden" negative charges within a nearby neutral piece of metal.

See the "water analogy" diagram above. The rubber barrier represents the dielectric. Yet electrical forces can reach across the dielectric, just as physical forces can be transmitted through a rubber barrier.

If you forcibly inject electrons into one plate of a capacitor, these electrons will repel the electrons hidden within the other uncharged plate, and these other electrons will be forced out of the capacitor's other terminal. However, if the other capacitor terminal is connected to nothing, then those electrons cannot leave the other plate. They will continue to repel the electrons in the first plate, and for this reason very few electrons can be forced into the first plate. The rule for most capacitors is: the current in both capacitor terminals is always the same. This means: if charge is injected into one capacitor plate, then an equal amount of charge is pushed out of the other capacitor plate, and if equal charge cannot leave the second plate, then we CANNOT force charge into the first plate.

If we ignore the space between the plates, the capacitor SEEMS to be a kind of conductor. However, it is a strange "conductor" where the two terminals are connected by electrical forces which reach across a narrow space. It is not a true conductor, but neither is it a simple insulator.

```
> Sir, I have asked the same to my undergraduate professors, but they find
>it too trivial to answer. Thus, I have never been able to understand
>this concept.
```

I think this concept is explained very badly in physics textbooks. In physics, a single metal sphere is considered to be a "capacitor," and two metal spheres with a large separation between them is also a "capacitor." Yet conceptually these are very different from capacitors used in electric circuits.

In both these situations, the flow of charge into one sphere NEED NOT BE EQUAL to flows of charge in the other sphere or elsewhere. The entire universe serves as an extra unseen capacitor plate. Yet in electronics, "capacitor" means only one thing: "two closely-spaced plates." As far as electronic equipment is concerned, capacitors only have two plates, and the current in one terminal must always equal the current in the other terminal. This is not true for two distant conductors, but this "general case" in textbooks is MUCH harder to understand. Physics textbooks examine the general case where the currents in the capacitor terminals are not equal, and the electrostatic coupling between the plates is not very strong. Conventional capacitors in electronic equipment are different: the electrostatic coupling between their plates is extremely strong, the electrostatic coupling to the earth is nearly zero, and the current in the terminals connected to the two plates is always equal. The charge on their plates MUST be equal and opposite, always. But in physics textbooks, you can have three coulombs on one metal sphere, and two coloumbs on another.

Here is an "electrical engineering" way to understand it. Suppose the capacitance between two parallel plates is X microfarads. Suppose we force some charge into one plate, but we do not connect the other plate to anything. In this case, the lines of electric force extend outwards from both plates to the earth. Important question: what is the capacitance of the "capacitor" formed by one plate and the distant earth? It is small. VERY small, possibly millions or even billions of times smaller than the number of microfarads existing *between* the two plates. Therefore, if we connect both capacitor terminals to a circuit and force charges "through" this capacitor, the voltage across the plates will rise slowly, but if we instead try to force the same current into only ONE plate (and leave the second plate disconnected), then the voltage between the capacitor and the earth will rise millions or billions of times faster for the same current. In other words, a two-plate capacitor has immensely more capacitance than a one-plate capacitor. In electronics we usually ignore the "one-plate" phenomena entirely, and imagine that capacitors are a strange kind of two-terminal conductor.

Here is a model which exposes the problem. Rather than imagining a capacitor to be like two metal spheres, imagine it to be like one sphere which is divided into two parts, where the gap between the two parts is extremely small, and the capacitance value between the two parts is far larger than the capacitance value measured between each part and the distant earth...

```
            ____  ____
         __/    ||    \__
        /       ||       \
      /         ||         \        "Engineer's Capacitor"
     |          ||          |
    |           ||           |      A spilt metal sphere with
```

```
    |            ||            |    a very narrow gap between
    |            ||            |    the two halves
    |            ||            |
     |           ||           |
      |          ||          |
       \         ||         /
         \__     ||     __/
            \____||____/
```

Above is a model of an "engineer's" capacitor, as opposed to the two spheres of the "physicist's" capacitor. Because of the narrow gap, it behaves very diferenly than two separate spheres.

```
          ______                ______
         /      \              /      \       The "Physicist's Capacitor"
       /          \          /          \
      |            |        |            |     Two separate metal spheres
     |              |      |              |
     |              |      |              |
      |            |        |            |
       \          /          \          /
         \______/              \______/
```

If we dump some excess charge onto one half of the engineer's capacitor, something strange occurs: half of the charge apparantly migrates to the other half of the device! The twin hemispheres behave as a single conductive sphere because any excess charge on one half of the gap will induce equal and opposite excess charge on the other half of the gap, and this leaves excess alike charges on the second half (which then spreads across the surface.) In physics terms, the capacitance BETWEEN the two hemispheres is very large when compared to the capacitance measured from each hemisphere to distant ground. The split-sphere device behaves almost as if it has a conductive connection between its two halves. This connection is as real as the connection between the ends of a resistor... yet it is made out of electrostatic forces in space, rather than being made out of carbon.

In my experience, the the two spheres of the "physicist's capacitor" cause distortion in physicists' concept of what the electronic component called "capacitor" really is.

Analogy: if we were talking about coils, how would physicists visualize electric transformers? They'd be very familiar with induced currents between pairs of distant air-core coils, yet they would be almost entirely unaware of of the strange effects arising with closely coupled coils of an iron core transformer. Power transformers

behave very differently than two widely-spaced air-core inductors. The above split-sphere "engineer's capacitor" is analogous to an iron-core transformer, while the "two-sphere capacitor" of the physics textbooks is analogous to a pair if widely separated coils. When the coupling between the two parts approaches 100%, everything starts acting very differently.

WHICH WAY DOES THE "ELECTRICITY" REALLY FLOW?

Electronics teachers and authors of textbooks are often chided for passing on an "error" to their students. Teachers promote the (wrong?) idea that electric current is a flow of positive particles in one direction, when supposedly it's really a flow of negative electrons going the other way.

In fact, the chiders are wrong. They labor under the misconception that "Electricity" is made of negatively-charged particles called electrons. This fundamental error leads most people to imagine that electric currents are *always* a flow of negative particles. Actually, in some conductors the electric currents are a flow of genuinely positive charges, while in others the flows are indeed negative particles. And sometimes the currents are both positive and negative particles flowing at once, but in opposite directions within the same conductor. We cannot arbitrarily decide which way the charges flow, since their true direction always depends on the type of conductive material.

Electricity is more than just electrons

"Electricity" is not made of electrons (or to be more specific, Electric Charge, which is sometimes called "Quantity of Electricity," is not made of electrons.) Charge actually comes in two varieties: positive particles and negative. In the everyday world of electronics, these particles are the electrons and protons supplied by atoms in conductors. Physicists may additionally deal with other charged particles: muons, positrons, antiprotons, etc. But the "electricity" in common electrical devices is limited to positive protons and negative electrons.

Because the negative particles carry a name that *sounds* like "electricity," people unfortunately start thinking that the electrons ARE the electricity, and they think that that protons (having a much less electrical name?) are not electrical. Some text and reference books even state this outright, saying that electricity is composed of electrons. Nope. In reality the electrons and protons carry electric charges of *equal* strength. If electrons are "electricity", then protons are "electricity" too.

Now everyone will rightly tell me that the protons within wires cannot flow, while the electrons can. Yes, this is true... but only true for metals. And it's only true for solid metals. All metals are composed of positively charged atoms immersed in a sea of movable electrons. When an electric current is created within a solid copper wire, the

"electron sea" moves forward, but the protons within the positive atoms of copper do not.

However, *solid metals are not the only conductors,* and in many other substances the positive atoms *do* move, and they *do* participate in the electric current. These various conductors are nothing exotic. They are very common, they all around us; as close to us as they can possibly be.

Non-electron Charge-flow

For example, if you were to poke your fingers into the back of an old-style television set, you would suffer a dangerous or lethal electric shock. During your painful experience there obviously was a considerable current directed through your body. However, *no electrons* flowed through your body at all. The electric charges in a human body are entirely composed of positive and negative charged atoms or "ions." During your electrocution, it was these charged atoms which flowed along as an electric current. The electric current was a flow of positive sodium and potassium atoms, negative chlorine, and numerous other more complex positive and negative molecules. During the electric current, the positive atoms flowed in one direction, while the negative atoms simultaneously flowed in the other. Imagine the flows as being like crowds of of tiny moving dots, with half the dots going in one direction and half in the other. The crowds of little dots move through each other without any dots colliding. The postive atoms behave like a proton, but a proton with an entire atom attached. The negative atoms behave like electrons which are dragging an entire atom along with them.

So, inside human flesh, which direction did the electric current REALLY go? Do we follow the negative particles and ignore the positive ones? Or vice versa, following the negatives? There is a simple answer, but first...

Batteries are another example of non-electron or "ionic" conductors. When you connect a lightbulb to a battery, you form a complete circuit, and the path of the flowing charge is *through* the inside of the battery, as well as through the light bulb filament. Battery electrolyte is very conductive. Down inside the battery, within the wet chemicals between the plates, the amperes of flashlight current appears as a flow of both positive and negative atoms. There is a powerful flow of electric charge going through the battery, yet no individual electrons flow through the battery at all. So, while the current is between the two plates of the battery, what's its *real* direction? Not right to left, not left to right, but in both directions at once. About half of the charge-flow is composed of positive atoms, and the remaining portion is composed of negative atoms flowing backwards. Of course in metal wires outside the battery, the real particle flow is only from negative to positive. But inside the battery's wet electrolyte, the charge-flow goes in two opposite directions at the same time. (And if we built a circuit from hoses full of salt water, with no metal conductors used, then *all* the current would be bi-directional.)

Two-way currents are common

There are many other places where this kind of positive/negative charge flow can be found. In the following list of devices and materials, electric charges found within conductors are a combination of movable positive and negative particles. During an electric current, both varieties of particles are flowing past each other in opposite directions.
TWO-WAY POS/NEG ELECTRIC CURRENTS CAN EXIST IN:

- batteries
- human bodies
- all living organisms
- the ground
- the ocean
- the sky (ionosphere)
- electrolytic capacitors
- aluminum smelters
- liquid mercury and solder
- ion-based smoke detectors
- electroplating tanks
- electrophoresis gels in research (esp. DNA testing)
- air cleaners, smoke precipitators
- particle beams
- the vertical "sky current" in the atmosphere
- gas discharge, which includes:
    - electric sparks
    - fluorescent tubes
    - sodium and mercury arc streetlights
    - neon signs
    - the Earth's Aurora
    - lightning and corona discharges
    - arc welders
    - Geiger counter tubes
    - thyratron tubes
    - mercury vapor rectifiers

This list is not so short. Again I ask you, what is the REAL direction of electric current? We cannot solve the problem by belittling it, or by pretending that two-way currents pertain only to something exotic, or pretend that it's separate from everyday life. Our own nervous system is based on two-way currents. We dare not think that a current in a wire is "real," while currents in human flesh are not.

Well, what is "current?"

To gain some insight, let's examine the details. When trying to understand electric circuits and electrical measurements, we need a simple way to take measurements of the important entity named Electric Current. But to measure currents, won't we first need to measure how much of the current is composed negative particles going one way, and positive particles the other? Yes, but we ONLY need this if we want to know EVERYTHING about the electric current. The flowing negatives and positives are usually not equal, and the speed of the positives in one direction is usually not the same as the speed of the negatives in the other. Electric current can be complicated! However, there is a cute trick we can pull in order to avoid having to look at the particles at all. And that trick holds the answer to the question.

Electric currents produce three main effects: magnetism, heating, and the voltage drop across resistive conductors. These three effects cover almost everything we encounter in electronics. And these three effects *don't care* about the amounts of positive and negative particles, or about their speed, their mass, their charge, etc. If a hundred positive particles flow to the left per second, this gives EXACTLY as much magnetism, heating, and voltage as a hundred NEGATIVE particles flowing to the right per second. (Note: this is because reversing the polarity of the particles reverses the current, and reversing the particle direction reverses the current again! Two negatives make a positive.) Magnetism, heating, and voltage drop together represent nearly every feature that's important in everyday electrical circuitry. Therefore, as far as most electrical devices and circuits are concerned, it makes no difference if the current is made of positive particles going one way, or negative particles going the other... or half as many negatives flowing backwards through a crowd of half as many positives.

Put simply, the "Ampere" doesn't care about the direction or speed of the flowing particles.

So, in order to simplify our measurements and our mental picture of Electric Currents, we cut away the unused parts of the picture. We make the negative particles positive, then add their current to any positive particles which were flowing forward. We stop thinking of current as being a flow of charges. Instead we *intentionally define* "electric current" as being a flow of exclusively positive particles flowing in one particular direction. We don't care about the real polarity of the particles. We don't care about their speed, and we don't care about their number. We ignore both the chemical effects and the effects of the velocity and direction moving particles. We ignore the collisions between positive and negative particles. All we care about is the total net charge

which moves past a particular point in the circuit. The real charges are too complicated to deal with, and the added complexity gets us very little information as long as we're only interested in voltage drop, magnetic fields, and heating.

Particle-flow is real, "Amperes" are not

Once we start ignoring the speed and direction of the charges, then we can easily build electrical instruments or "amp meters" which measure the Conventional Electric Current in terms of the magnetism which the charge-flow creates... or by the voltage drop which appears across a resistor, or by the temperature rise being created in a calibrated piece of resistance wire. These three types of meter will agree that a "current" is a "current" regardless of the particle polarities and flows. Then we can use these meters everywhere. In nearly every situation they will tell us all we could ever want to know about flows of charged particles in any circuit. An amp-meter might not be appropriate when used in an exotic physics experiment. It won't paint the correct picture when designing electron beams inside vacuum tubes. It cannot detect real current, instead it only measures our conventionally-defined simple current. But for more than 99% of electricity and electronics, the direction of the particles is irrelevant, and an ammeter tells us the so-called "real" current while hiding the true particle flows.

Or to put it simply: we pretend that "electric currents" are always composed of POSITIVE particles, so that any negative currents are defined as positive particles flowing backwards rather than negative particles flowing forwards.

Confusing students for two hundred years

We do cause some problems by choosing a positive charge convention. For example, what happens if we all spend many years thinking in terms of such simplified "electric current?" Might we eventually start believing that this oversimplified concept of positive electric current is REAL? Yet it's not real, it's simply one way to simplify things. There's a genuine difference between the simplified picture versus the actual particle flows. The Amps would not quite match a visual picture of moving particles. But if we truely believe that the amperes are real, we might start to doubt the existence of flowing charges. We might start to see "Electric Current" itself as a sort of abstract, invisible, difficult-to-image thing. We might lose track of the facts that electric current is an actual flow of matter. We might lose track that there are real, visible particles flowing along inside that circuit, or that these particles have an actual average speed, mass, and direction.

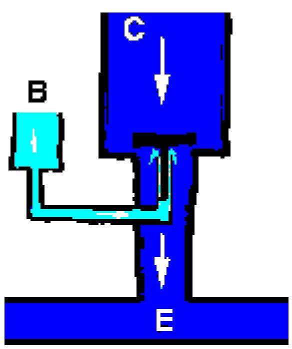
Because "amperes" are so incredibly useful, the simplified interpretation of Current takes over and becomes more real than reality. It allows us to understand parts of physical science which otherwise might be too complicated to imagine. But in letting the positive charges take over, some nagging questions are left behind, such as "WHICH WAY DOES THE ELECTRICITY **REALLY** FLOW?" (grin!)

PS
This over-simplified fake electric current measured by ammeters is commonly called

"Conventional Current." The link give 16,000 google hits. By convention, we define the flowing charges to be positive. Yet something is missing! Nobody talks about the "Conventional Charge!" No google hits! The conventional current must be a flow of conventional charge, so first we should teach our students about the existence of oversimplified charges, "conventional charges," charges which we pretend are inside all the wires. If we did this, then "conventional current" would be much easier to accept, no?

How do Transistors Work?

Return to SatCure-Focus Home page.



Thousands of textbooks have been written to explain electronics and I haven't found a single one that can explain the operation of a transistor. They all make it seem so complicated!

Let's see if I can do better. Here is a picture of a transistor. My transistor runs on water current. You see there are three openings which I have labelled "B" (Base), "C" (Collector) and "E" (Emitter) for convenience. By an amazing coincidence, these also happen to be the names used by everyone else for the three connections of a transistor!

We provide a reservoir of water for "C" (the "power supply voltage") but it can't move because there's a big black plunger thing in the way which is blocking the outlet to "E". The reservoir of water is called the "supply voltage". If we increase the amount of water sufficiently, it will burst our transistor just the same as if we increase the voltage to a real transistor. We don't want to do this, so we keep that "supply voltage" at a safe level.

If we pour water current into "B" this current flows along the "Base" pipe and pushes that black plunger thing upwards, allowing quite a lot of water to flow from "C" to "E". Some of the water from "B" also joins it and flows away. If we pour even more water into "B", the black plunger thing moves up further and a great torrent of water current flows from "C" to "E".

So what have we learned?:

1. A tiny amount of current flowing into "B" allows a large amount to flow from "C" to "E" so we have an "amplification effect". We can control a BIG flow of current with a SMALL flow of current. If we continually change the small amount of water flowing into "B" then we cause corresponding changes in the LARGE amount of water flowing from "C" to "E". For example, if we measure the current flow in gallons/minute: Suppose 1 gallon/minute flowing into "B" allows 100 gallons/minute to flow from "C" to "E" then we can say that the transistor has a "gain" or "amplification" factor of 100 times. In a real transistor we measure current in thousandths of an Ampere or "milliamps". So 1mA flowing into "B" would allow 100mA to flow from "C" to "E".

2. The amount of current that can flow from "C" to "E" is limited by the "pipe diameter". So, no matter how much current we push into "B", there will be a point beyond which we can't get any more current flow from "C" to "E". The only way to solve this problem is to use a larger transistor. A "power transistor".

3. The transistor can be used to switch the current flow on and off. If we put sufficient current into "B" the transistor will allow the maximum amount of current to flow from "C" to "E". The transistor is switched fully "on".

If the current into "B" is reduced to the point where it can no longer lift the black plunger thing, the transistor will be "off". Only the small "leakage" current from "B" will be flowing. To turn it fully off, we must stop all current flowing into "B".

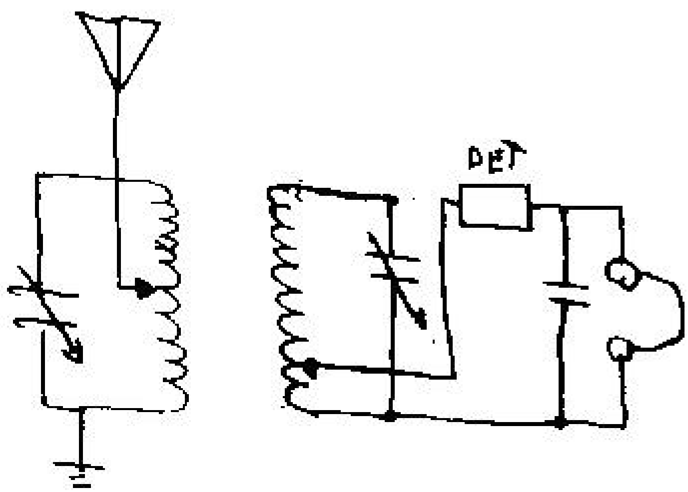
In a real transistor, any restriction to the current flow causes heat to be produced. This happens with air or water in other things: for example, your bicycle pump becomes hot near the valve when you pump air through it. A transistor must be kept cool or it will melt. It runs coolest when it is fully OFF and fully ON. When it is fully ON there is very little restriction so, even though a lot of current is flowing, only a small amount of heat is produced. When it is fully OFF, provided we can stop the base leakage, then NO heat is produced. If a transistor is half on then quite a lot of current is flowing through a restricted gap and heat is produced. To help get rid of this heat, the transistor might be clamped to a metal plate which draws the heat away and radiates it to the air. Such a plate is called a "heat sink". It often has fins to increase its surface area and, thereby, improve its efficiency.

A D V E N T U R E S in C Y B E R S O U N D

A 'Selective' Razor Blade Crystal Radio from Gnome Technologies (see also a matching 'Sensitive' Set)

Introduction

The use of two independent tuned circuits is main variation from the "classic" crystal set. While this means roughly twice the work and parts, the increase in selectivity was worth it for my signal-saturated urban location.



The antenna and detector inductors are identical - about 60 turns of #24 copper wire on a 2.25" outside diameter PVC water pipe. To increase selectivity, the inductors are NOT wound on the same form, but rather are loosely coupled sitting side-by-side.

Taps every 5 turns allows experimentation with a wide range of detectors and antenna configurations. The total inductance is measured to be around 160 uH. To make coil winding easier, I covered the PVC pipe with double-sided tape.

Variable capacitors are the old air-spaced metal type, cannibalized out of a busted tube-radio from the 1950's. Rather than drilling countersunk holes in the wood, the caps are epoxied to aluminum plates, which are then mounted on the wood. Both are the 35-365 pF type.

The headphones are the classic old-style magnetics, with a coil resistance of around 2K. Modern headphones will not work with a crystal radio. I was lucky to find some vintage-1940 units tucked away in storage in our local physics department. The capacitor across them is .001 uF; it's probably not needed but I threw it in for good measure.

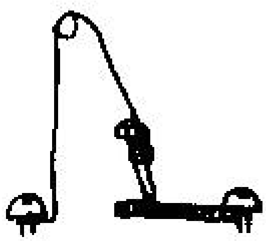
Antenna and ground... suck. It's about -35 C where I'm at, and I don't have the heart to string a proper L-shaped long wire. About 20m of stranded copper wire strung along the fence (end fed) is the antenna for now. Ground is even worse- the screw that holds the plastic plate onto an electrical outlet. Better antenna and ground are coming once things thaw out.

Detector

This is where things get fun. I started with the typical 1N34 germanium diode. Very sensitive, nothing to tinker with.Boring.

My general-purpose detector assembly is a safety pin mangled into a U shape, with a piece of 3H pencil bound to it by copper wire and soldered in place. The other contact is

a big brass washer, which bits of rock and metal can use as a "solid" connection to the coil tap. It looks something like this:



My dad told me about when he was a kid (1940's) tinkering with a radio using razor blades and pencil lead. This started a quest for other materials to use as a detector:

XACTO BLADE

Not having any razor blades handy, I tried anXacto (tm) blade. It works, but takes a VERY light touch, the pencil just brushing against the surface of the blade. Sensitivity is good, but it seems kind of fickle and drifts due to the precarious nature of the contact.

IRON RUST

A more reliable detector substance is iron rust. We had some iron discs laying around the lab, so I just put some water on them and left them overnight. The resulting patches of orange are quite sensitive. These disc detectors need a fair bit of contact pressure from the pencil lead. Probably a rusty razor blade would do just about the same.

MAGNETITE

I also got some magnetite (Fe_2O_3, also called lodestone) - kind of a refined version of the rust detector. This is roughly the same performance; one could probably make a "fixed" detector using this.

RAZOR BLADE

I found a rusty razor blade; good sensitivity, and it's less picky about the junction contact than the Xacto blade.

N-TYPE SILICON

This is cheating, but a piece of N-type silicon (simply broken off a boule used to make IC wafers) makes an excellent detector, giving almost as strong a signal as with a germanium diode.

FUSED SILICON

Also located some fused silicon (Fisher Scientific S-164), which also a wonderful detector- very sensitive.

IRON PYRITE

A local toy store sells a wide range of minerals. Pricey (a small piece was $1.00), but they had iron pyrite. About the same sensitivity as magnetite.

COPPER OXIDE

Copper oxide, in the form of old vacuum sealing rings, is also a sensitive detector substance.

This is a "renewable" detector- sanding the copper with some fine-grit sandpaper until it's shiny gives best results. Possibly the fresh, very thin oxide layer is most sensitive. Once again precarious nature of the contact makes using it tricky.

Other materials to try, as soon as I get my hands on them include:

GALENA (lead sulfide)

Recently read that it's possible to make your own Galena using lead and sulfur. This is worth looking into!

CARBORUNDUM (silicon carbide)

I've tried bits of grinding stones and wheels, but they seem to be carborundum laced with some kind of binding agent, and don't have any semiconductor properties. Also a bias voltage in series with the headphones will be needed to compensate for the large forward conduction potential of carborundum.

ERUSSITE (lead carbonate)

MOLYBDENITE (molybdenum disulfide)

LEAD PEROXIDE

ZINC PEROXIDE

Sensitivity

Sensitivity and selectivity are always at odds in a crystal radio. This unit is designed for good selectivity, so the sensitivity leaves a lot to be desired. It can only pick up our 5 strongest local AM stations, and nothing else.

Selectivity

Selectivity is actually good. We have two CBC stations, one in French at 1050 kHz, and English at 990 kHz. I like both, and the French is the strongest signal on the whole band; the tuned antenna and loose coupling lets me pick out the English CBC station easily.

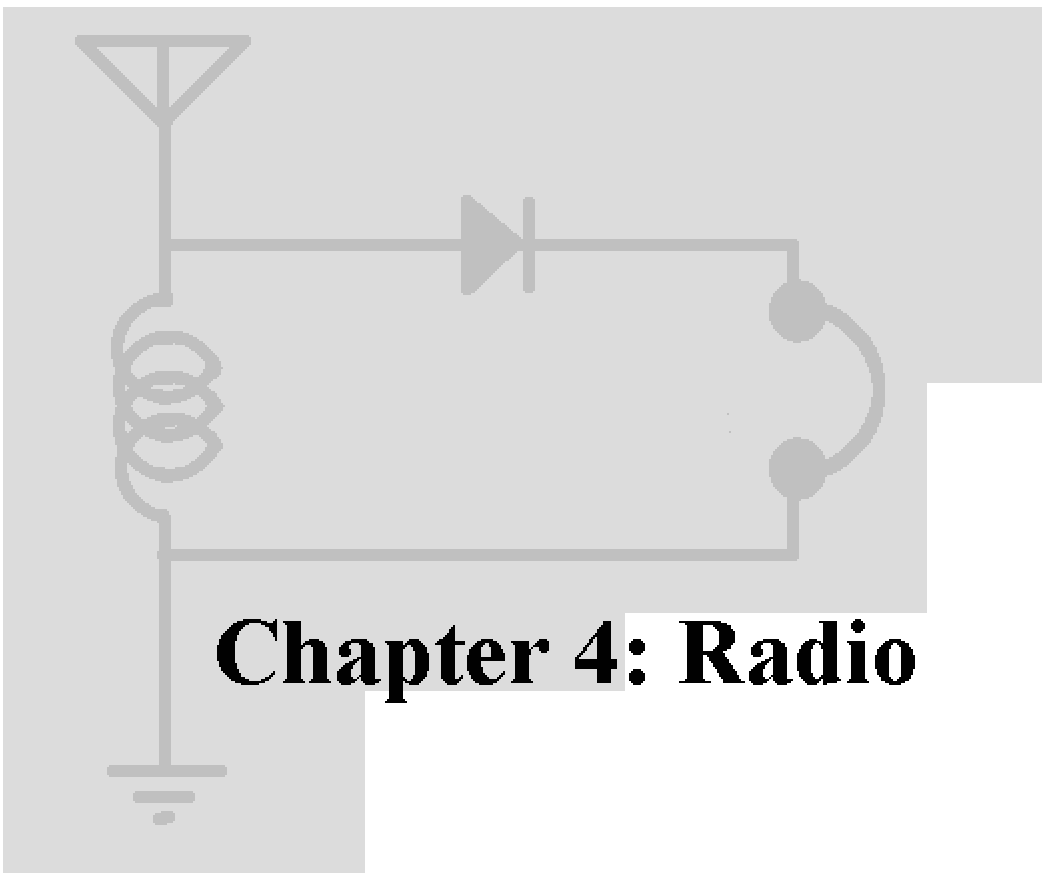
Tuning the radio is kind of tricky until you get used to it. With my antenna, using the bottom tap on the antenna inductor, the two capacitors roughly track to resonance. Turning both at the same rate will let you catch what stations are out there, then tweak each capacitor on it's own to increase signal strength. There is little mutual inductance so you can tune each circuit independently.

The antenna tap has to change depending on frequency. This makes sense- the antenna-ground system presents not only a resistance but also some capacitance, which will de-tune the resonant circuit. The high end of the AM band requires a tap closest to ground, while the low part (700 kHz and below) needs the tap at the top. Of course taps towards the bottom of the coil increase selectivity and decrease sensitivity.

With the antenna tapped at the top of the inductor, the tuning capacitor C needs to be set to around halfway in order to receive a strong station at 680 kHz. This gives an antenna capacitance of around 160 pF.

Conclusion

In our age of instant point-to-point communication it's nice to go back to basics. My next project is going to be a crystal shortwave radio, but that will probably have to wait until spring when I can string a proper antenna.



Chapter 4: Radio

Building a crystal radio out of household items.

A piezoelectric earphone

The most difficult part of building a crystal radio is building an efficient earphone that can convert the tiny electrical signals into tiny sounds that our ears can hear. Our first radio used a telephone handset for an earphone, and that works quite well. But another type of earphone is available that fits in the ear so you don't have to hold it. It is also more sensitive than the telephone handset.

In order to convert very faint electrical signals into sound, we need a very sensitive earphone. The kind of earphones used in transistor radios or CD players will not do. Those are meant to be driven by a signal loud enough to drive a speaker, and are not sensitive at all.

We will talk later (in the scientific part of this chapter) about *impedance* and what it means. For now, we will just say that a sensitive earphone has a very high impedance, which is measured in ohms. A speaker has a low impedance, usually about 8 ohms. A sensitive earphone built around an electromagnet (we will build one of these later) might have 2,000 ohms. The telephone handset earphone is of this type, although it has only a few

hundred ohms of impedance, and will not be as loud as a more sensitive device.

The crystal earphone we will play with in this section has over a million ohms of impedance, and is very sensitive.

A crystal earphone (more properly called a piezoelectric earphone, pronounced pee-zo) is made of a material that changes its shape when connected to a source of electricity. Some crystals such as quartz, and Rochelle's Salt are piezoelectric. Some ceramics (such as those made with barium titanate) are also piezoelectric. Our piezoelectric earphone is made of a disk of brass that is coated with barium titanate ceramic. When electricity is connected to it, the ceramic bends the brass disk, and we can hear the vibrations this causes in the air.

To make piezoelectric earphones easier for our readers to find, we now offer them in our catalog.

To demonstrate just how sensitive a crystal earphone is, try this experiment: with the earphone in your ear, touch the two wires together. You will hear a sharp click as electrons move from one wire to the other. If the earphone came with a jack on the end instead of two bare wires, you will need a piece of metal such as a spoon to connect the two metal parts of the jack.

One detail about such a very sensitive earphone is important in building a crystal radio. A sensitive earphone does not use very much current to create the sound. Another way of saying this, is that not much current is going through the earphone. Our radio needs a certain amount of current to flow through the diode in order to work.

When substituting a piezoelectric earphone for an earphone made with a coil of wire, we must provide a way for some current to bypass the earphone. We do this by putting a resistor or a coil in parallel with the earphone (parallel means that the resistor or coil is attached to the same two places that the earphone wires are attached).

The resistor can be anything in the range of 1,000 ohms to 100,000 ohms, and can be a piece of graphite out of a pencil, or a couple hundred coils of fine wire around a nail.

A Germanium diode detector

The second part of our radio, after the earphone, is the detector. A detector is something that picks the audio frequencies out of a radio wave, so they can be heard in the earphone. We will learn more about how they work in the scientific part of the chapter later on.

Our first detector will be store-bought. Later we will replace it with detectors we build ourselves out of things we find around the house, like lead pencils, baking soda, razor blades, rocks, all kinds of things.

The detector we will use first is a Germanium diode. The diode we want is called a 1N34A by the people who name diodes. This diode has some properties that make it particularly suited to our purpose, namely that it works at lower voltage levels than most other common diodes. Since the voltage in our radio comes from weak little radio waves, we need all the help we can get.

We now carry this diode in our catalog, to make it easier

to obtain. Radio Shack used to carry them, but they no longer have them in their stores.

We are now ready to build our simplest radio.

A very simple radio with two parts

First let me warn you that this first little radio may not work in your location. It relies on having a very strong local radio station to overcome the limitations of such a simple radio. If it does not work where you are, you can either build its cousins that we will discuss later, or you can drive out closer to a local radio station, and try it there. But because it is so simple, you might try building it just to see what you might be able to pick up.

If your earphone has a jack on the end, cut it off, so you have two long wires coming from the earphone. If the wires are twisted around each other, that is OK, since we only need them to be separate at the very ends.

Remove the covering (called insulation) from the ends of the wires to expose an inch of bare wire. Often you can do this with your fingernail, but a tool called a wire stripper is made for this purpose, and can usually be purchased at the same place you got the earphone or the diode.

Wrap one bare wire around one of the diode's wires. Use some tape to keep it in place. If you know how to solder, you can solder the wires together, but it really isn't necessary for now.

Tape the other diode wire to a cold water faucet. This makes a good connection to the ground, and is thus called a 'ground' connection.

Hold the remaining free bare wire of the earphone in your hand. This makes your body into the antenna for the radio. Put the earphone in your ear. If you are close to a strong AM radio station, you will be able to hear that station faintly in the earphone. You may hear more than one station at once.

If you can't hear anything, you might try a better antenna. You can tape the wire you were holding to a metal window screen, or a long wire. If one end of the long wire is thrown up on a roof or in a tree, you might get better results. Another good antenna is an outdoor TV antenna. Just touch the free earphone wire to one of the antenna terminals where it comes into the TV. If you have a good antenna, you may be able to eliminate the ground connection, using your body as a ground instead, by holding the free diode wire in your hand.

Another simple radio with two parts

Our simple radio has two main drawbacks. One is that the signals are very faint, and can only be heard if you are close to a radio station's transmitting antenna. The other is that you hear all of the strong stations at once, and it is hard to pick out just one song or voice from the mixed up jumble. The first problem is called the 'sensitivity' of the radio. Our radio is not very sensitive. The second problem is called the 'selectivity' of the radio. Our radio is not very selective.

We can solve both problems by using a trick called

resonance.

Resonance is a way of taking a little bit of energy, and using it over and over again, at just the right time, to accomplish a big task. We use resonance when we push someone on a swing. It would take a lot of work to lift someone several feet in the air, but we can do this easily on a swing by giving a little push over and over again at just the right time. Timing is important: if we push at the wrong time, the swing can actually lose energy instead of getting higher.

When an opera singer uses her voice to shatter a wine glass, she is using resonance. Her voice gives the glass a little push at just the right time, over and over again, until the glass is moving so far that it shatters. In a similar way, we can slosh all the water out of a bathtub by moving a hand in the water at just the right back and forth speed. Each time the hand moves, the water climbs a little higher, until it is over the top of the tub.

Radio waves can act like the sound waves of the singer's voice, or like the waves in the bathtub. Radio waves can cause electrons to move back and forth in a wire, just like the water in the tub. If the radio waves are moving back and forth at the right frequency, then the electrons in the wire will just be crowding towards one end of the wire when the radio waves start moving them back to the other side. Just like the water in the tub, the electrons will crowd higher and higher at the ends of the wire. These electrons can do work, like moving the brass disk in the earphone to create sound.

We can use resonance to build a radio that can pick up only one station at a time, and make a louder sound in the earphone. This radio will also have some drawbacks (for one thing it will be over 1,000 feet long!) but we will solve these problems in the next radio we build.

Suppose we pick a local radio station we want to hear. For this example we will choose 740 kilohertz on the AM dial. We now need to figure out how long the wire must be to resonate at this frequency. Radio waves travel at the speed of light. This radio wave is going back and forth 740,000 times per second. This means the wave needs to go about a quarter of a mile in one direction, then turn around and go back again, over and over. The actual formula for figuring out how long the wire should be is

$$\frac{936 \text{ feet}}{\text{Frequency in Megahertz}}$$

or, for our example:

$$\frac{936 \text{ feet}}{.740}$$

or about 1264 feet.

To make our radio, we take half of the wire (632 feet) and attach it to one end of the diode. We attach the other half of the wire to the other end of the diode. We attach one earphone wire to one side of the diode also, and the other earphone wire to the other end. We put the long wire up in the air by attaching each end to a tree (the trees must be about 1264 feet apart). Then we put the earphone into our ear, and listen to the radio.

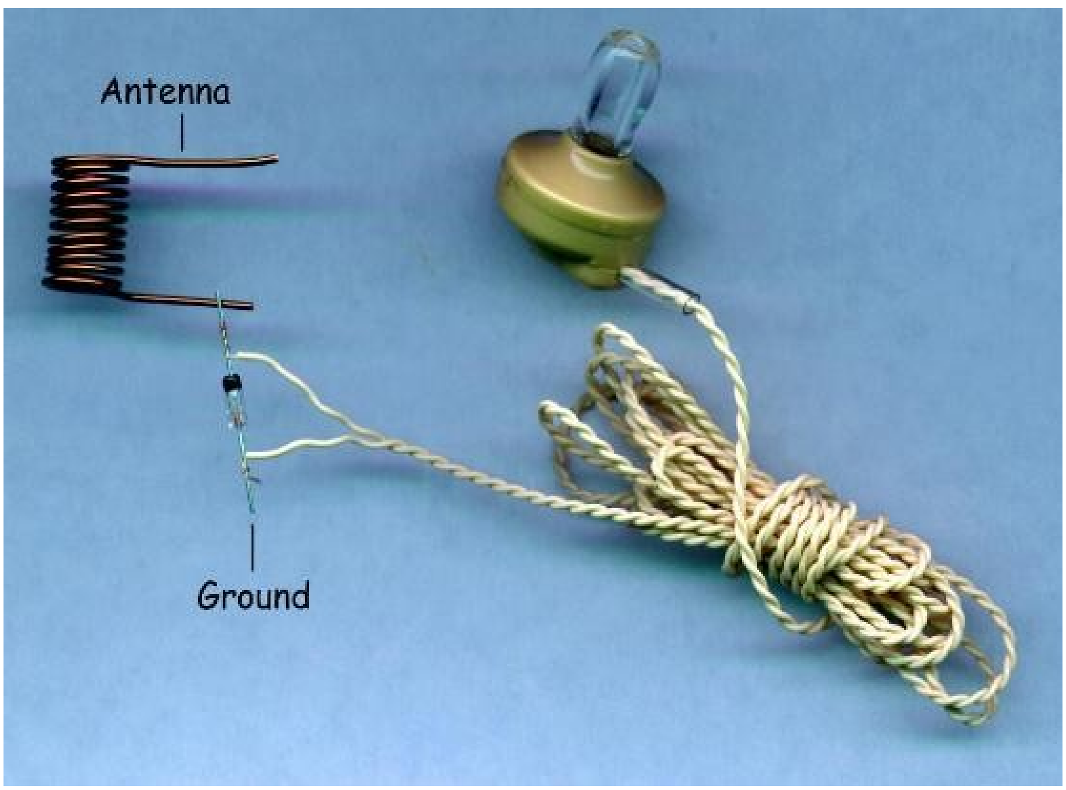
Now I can think of a couple problems with this radio. It is not the most portable radio. Also, in order to change the station, we need to make the wire longer or shorter.

One solution to the portability problem is to coil the wire up by winding it on a box or a cylinder. Then we can solve the tuning problem by attaching the diode and earphone

to the coil at different places (easy to do now that the whole wire is in one small place).

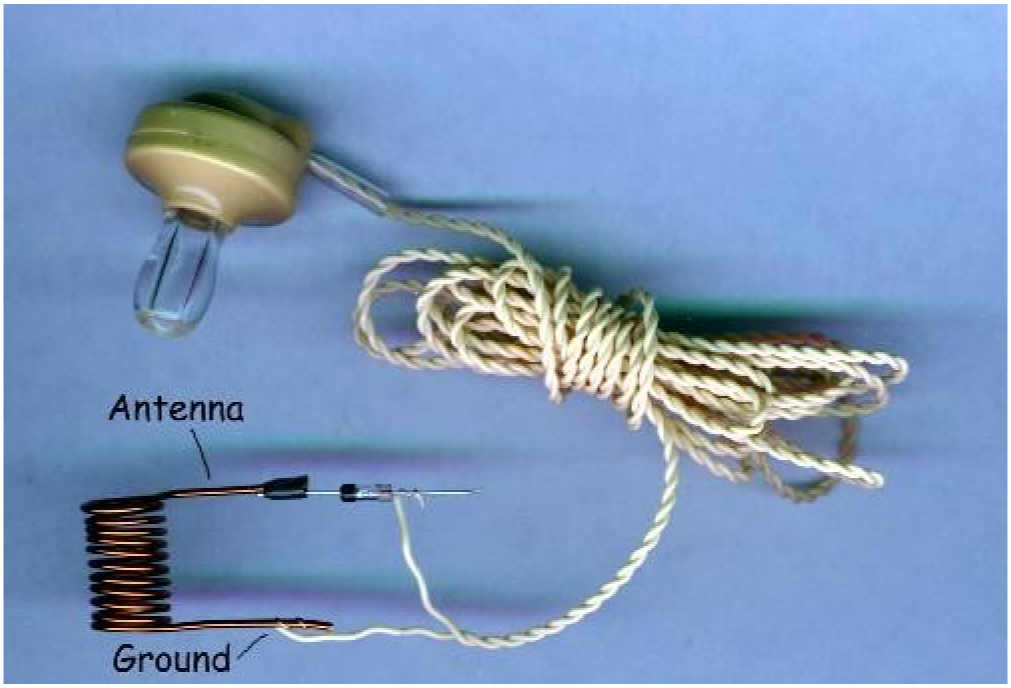
A simple radio with three parts

There are several ways to connect a coil of wire to a diode and earphone to make a radio. In the photos below, we show two possibilities that work.



The photos do not show the antenna and ground connections, but instead indicate where they would be

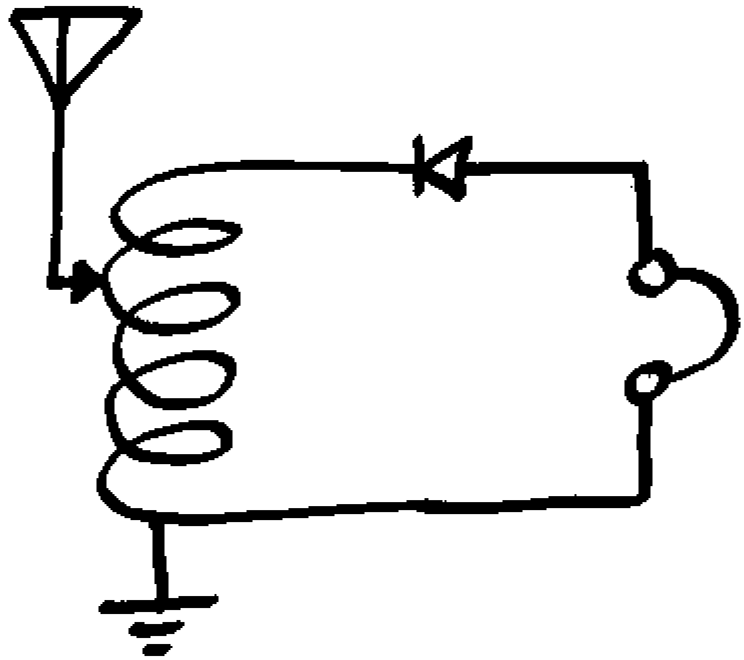
attached.



The coil in the photos is also dramatically simplified. A real coil for the AM radio frequencies would be somewhat larger, as we saw when we built our first radio using the plastic bottle.

Often photographs show so much detail that the important parts are easily missed. By using a simplified drawing, we can accentuate the important parts of the circuit and leave out unimportant or distracting details that can interfere with getting the point across.

A simplified drawing of a circuit is called a *schematic*. A schematic for a simple crystal radio might look like this if drawn on a napkin at a party:



The symbol for a coil looks like a spring. The symbol for an antenna looks like someone used a coat hanger. The symbol for headphones looks like the old fashioned ear-muff style (which are great for crystal radios, since they block out ambient noise in the room). The symbol for the ground looks like what a cartoonist would draw under a cartoon character to represent the earth.

Note that the antenna is attached to the coil in the middle by a small arrow. This indicates that it is attached to a tap in the coil. An arrow is used to indicate a connection that can move, like our clip lead.

The symbol for the diode looks nothing like the little glass tube with wires coming out. Instead of represeting what the diode *looks* like, it represents what the diode *does*.

A diode is a one-way valve for electricity. The electric

current flows through the diode in one direction, but is blocked if it tries to flow in the other direction. We will find out why this is important later, when we learn why the radio works. But for now, we will concentrate on building a radio that will let us hear one station at a time, with reasonable loudness.

Power from radio waves -- hooking up a meter to measure the voltage and current

It is useful at this point to be able to measure the effects of changes we make to the radio. We can just use our ears and try to remember how loud it used to be, but it is easier to read a meter, and remember a number. With a meter connected to the radio we can adjust the tuning for the highest meter reading, or make other adjustments as we add new components or replace purchased components with ones we make ourselves.

The meters must be sensitive to very small changes in the amount of electricity flowing in our radio. We will be measuring *current* mostly, but we will add a voltmeter as well, so we can calculate the total amount of energy we are receiving.

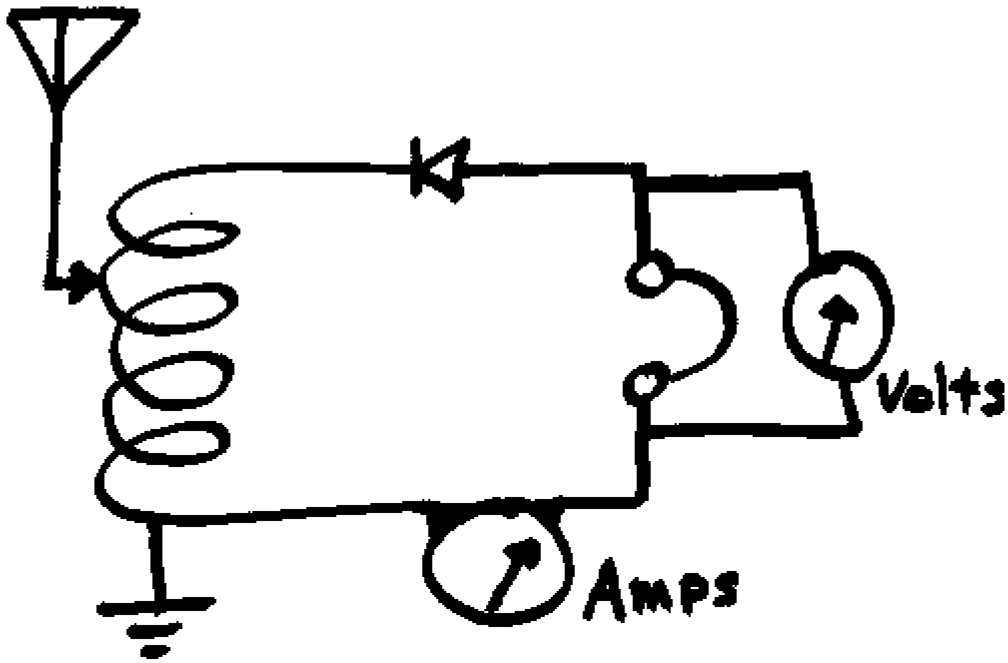
Current is the flow of electricity through the circuit, and it is measured in amperes, or amps for short. Voltage is the pressure that pushes the current through the wires. If electicity were water, current would be the amount of water flowing (gallons per minute), and voltage would be the water pressure in pounds per square inch.

Since the amount of current is very small, we will use a meter that measures current in micro-amperes, or at most

small fractions of a milliampere. Some examples of microammeters and milliammeters can be seen in the photo below:

To measure the current in our radio, we will need to have the current flowing through the meter. To do this, we connect the microammeter between the earphone and the ground connection, so that any electricity that is going to flow throught the earphones to make noise is going to have to flow through the meter also. The meter can be connected in two ways, one is forward and one is backward. If the meter is connected backward, the needle will start reading below zero. If this happens, just reverse the connections, so the needle reads above zero.

To measure the voltage, we connect the meter to both of the earphone wires. The schematic diagram now looks like this:



If you have a good antenna, or a strong radio station nearby, the ammeter might read more than 50 microamps. If you have a short antenna, you might get only 5 microamps and still be able to hear the station clearly in the headphones. I put up a 200 foot antenna between two trees over my house, and tuned to a 50,000 watt station about 30 miles away, and now I get 175 microamps of current through my meter. I put the earphone to the mouth of a cone (like a megaphone) and I can clearly hear the radio from across the room when the house is quiet. It doesn't sound as nice and clear as it does with the earphone right up to my ear, but I can follow a conversation easily (it's an all-news station).

The voltmeter in the same radio reads 125 millivolts.

Since watts (the measure of how much power we have) is the voltage multiplied by the amperes, we have 0.000175 times 0.125, or 0.0000218 watts, or about 22 microwatts. The station is putting out 50 killowatts, and we are receiving one ten billionth of that power, yet we can hear it across the room.

Try different lengths of antenna, and watch the current go up as the longer antennas catch more of the power from the radio station. Try more that one antenna. Try connecting the ground wire to different things that are connected to the ground, such as pipes, metal fences, etc. As you try each test, make sure you tune the radio again, because your changes may affect the tuning.

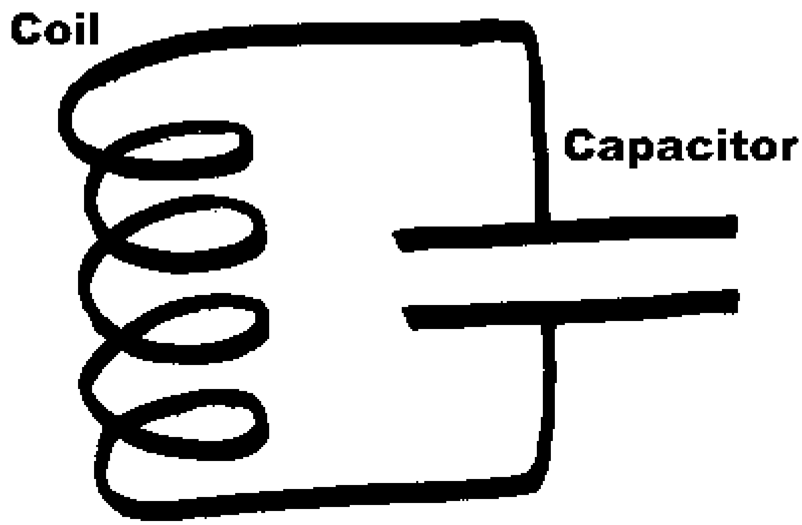
Adding a capacitor (or three)

As you tried different antenna lengths, you may have noticed that you had to move the tap on the coil in order to get the station at its loudest. To understand why this happens, and how we can use an understanding of it to improve our radio, we must first understand *capacitance* and how it affects the tuning coil.

A capacitor is simply two pieces of metal with an insulator between them. If a capacitor is connected to a battery, the battery will push electrons onto one piece of metal (called a *plate*) and draw electrons from the other piece of metal. If we remove the battery, the electrons can't go anywhere, so one plate of the capacitor will have more electrons than the other plate.

If we connect the two plates together with a wire, the electrons will rush from the plate that had too many (because electrons have the same charge, and thus repel each other like the north poles of two magnets) to the plate that had fewer electrons. As the electrons rush from one plate to the other, we can make them do work, such as light a light bulb. In this way, the capacitor seems to store the electricity from the battery, for use at another time when the battery isn't there.

Now suppose we connect a coil and a capacitor together like this:



Suppose also that the capacitor has been charged by a battery so the top plate has more electrons than the bottom plate. When we connect the coil, the excess electrons in the top plate immediately start traveling through the coil to get to the plate that has a shortage of electrons.

As the electrons travel through the coil, they create a magnetic field, (remember 'coil' is just another word for

'electromagnet'). The magnetic field grows until the plates on the capacitor have equalized. At this point you would think the current would stop flowing in the coil. But the magnetic field that built up when the current flowed through the coil now starts to collapse.

Just as moving a magnet past a coil will generate a current, a collapsing magnetic field around a coil creates a current too. The current is in the same direction as it was when the magnetic field was created, so the coil ends up pushing electrons onto the bottom plate of the capacitor, and stealing them from the top plate.

By the time the magnetic field around the coil has completely collapsed, the bottom plate of the capacitor has a surplus of electrons, and the top plate has a deficit. You can guess what happens next.

The electrons start flowing back into the coil, this time from the bottom plate to the top. The coil starts building up a magnetic field again, but since the current is now going the other way, what used to be the north pole of the magnetic field is now the south pole, and vice-versa.

The field grows until the capacitor has equalized, then it collapses, and pumps electrons into the top plate of the capacitor. We are now back where we started, and the whole process starts over again!

The coil and the capacitor are resonating, just like the child on a swing, or the water in a bathtub. In fact, this circuit is called a 'tank circuit', like a tank full of water that sloshes back and forth.

We can control the frequency of the oscillations in two ways. We can make the coil larger or smaller, or we can

make the capacitor larger or smaller. The coil we built for our radio has taps, which have the effect of making the coil shorter or longer, depending on which tap we connect to the antenna.

Our radio has a coil. But it doesn't have a capacitor. Or does it? Actually, the antenna itself is acting like a capacitor. The capacitance of the antenna is reacting with the *inductance* of the coil to resonate at the frequency of the radio station.

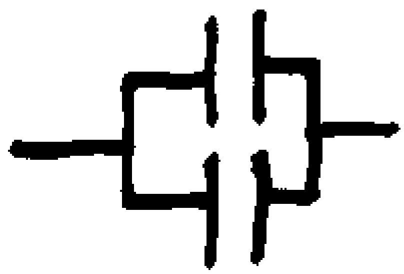
When we change the length of the antenna, it is like changing the size of the capacitor. This is why changing the length of the antenna changed the tuning of the radio, forcing us to move to a different tap on the coil in order to listen to the same station.

There is another way to change the capacitance of a capacitor. We can change the distance between the two plates. If the plates are closer together, the excess electrons on one plate are attracted to the other plate, because when the negatively charged electrons were removed from that plate, it was left with a positive charge.

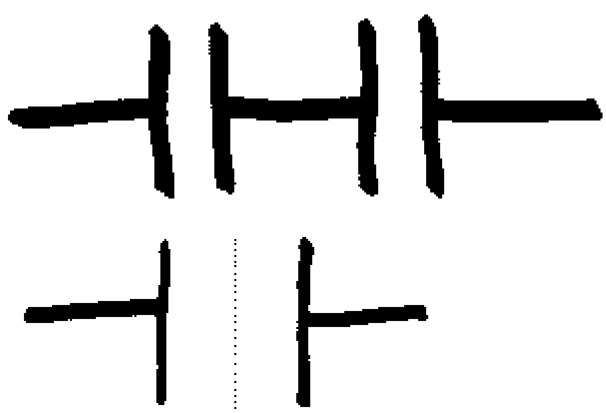
Because the electrons are attracted to the positive charge, we can pile more of them together, storing more energy. In a similar fashion, when we make a capacitor with the plates farther apart, the positive charge is farther away, and can't help to pull as many electrons onto the negative plate. Thus the amount of energy we can store is less, and we say the capacitor has less *capacity*

We can combine capacitors to raise or lower the capacitance, now that we know how capacitors work. If we put two capacitors together in parallel, we can increase the capacitance, because the top plates are connected

together, and the bottom plates are connected together, it is just as if we had one capacitor with large plates.



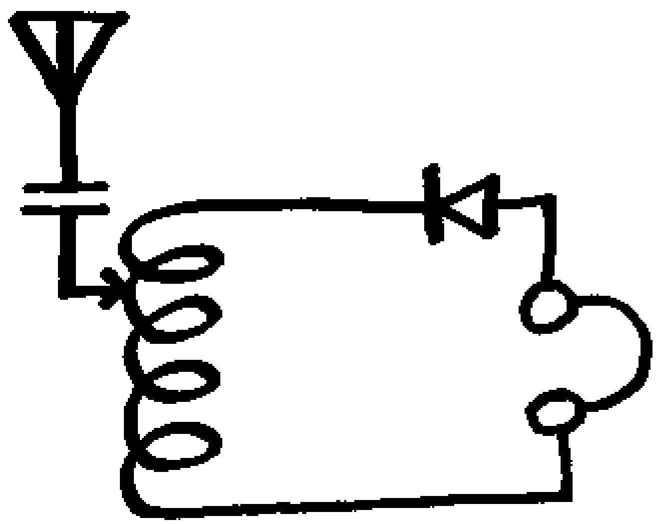
If we connect the capacitors in series, it has the effect of making the plates of the capacitor be farther apart. This can be seen in the illustration below. The bottom plate of one capacitor is connected to the top plate of the other. Electrically, this is the same as making the two plates into one plate in the middle of a capacitor that has twice the distance between the outer plates. The phantom inner plate has no effect, and is drawn as a dotted line in the bottom illustration.



We now know enough about capacitors to use them in our

radio. We can use a small capacitor between the antenna and the coil to lower the capacitance of the antenna. This will allow the coil to tune to stations that are higher in frequency. The capacitor is in series with the capacitance of the antenna, so the total capacitance is lower.

The circuit now looks like this:



Building your own capacitors

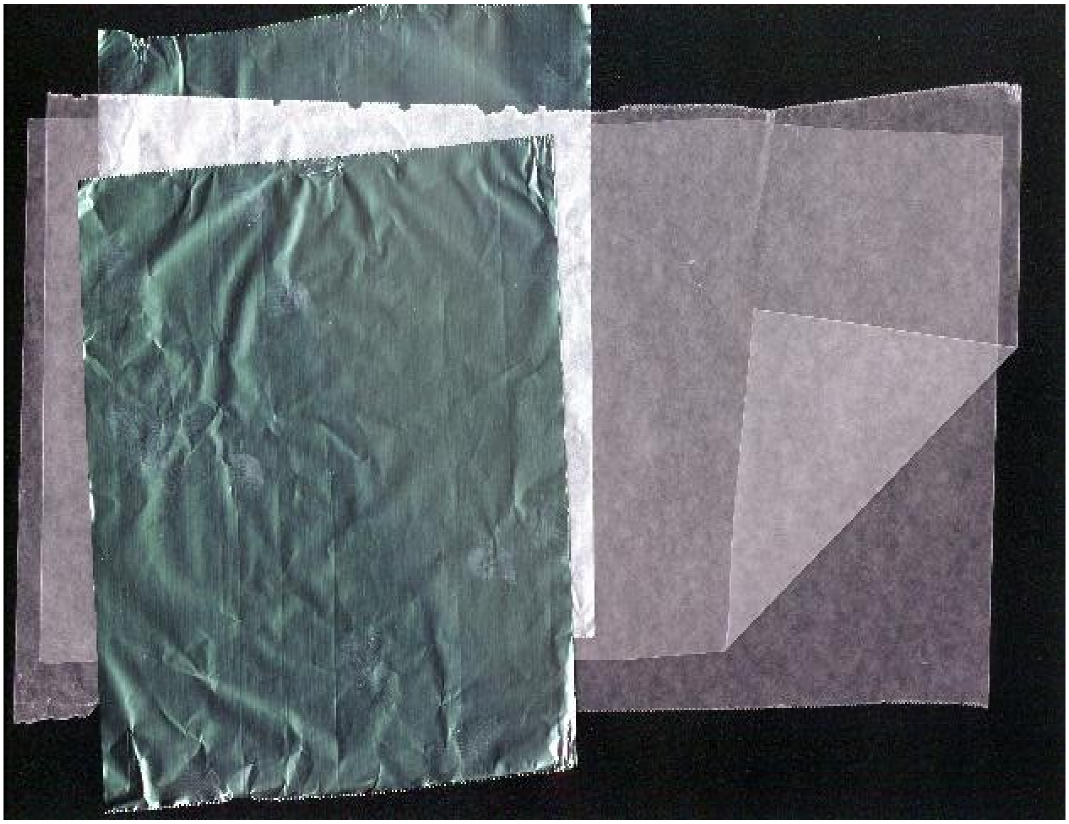
Capacitors are easy to build in the kitchen out of aluminum foil. In fact, our first capacitor will simply be two sheets of foil tucked into a paperback book, with one page separating them, as if they were two bookmarks.

This quick capacitor has advantages and disadvantages. It is quick and easy to build, it can be easily adjusted to vary the capacitance by simply sliding one of the foil strips out of the book a little at a time, thus reducing the capacitance. On the other hand, it is bulky, and comes apart easily, and will change its capacitance when you press down on the book, squeezing the pages closer together. Lastly, it can change capacitance slightly on humid days as the pages of the book absorb moisture.

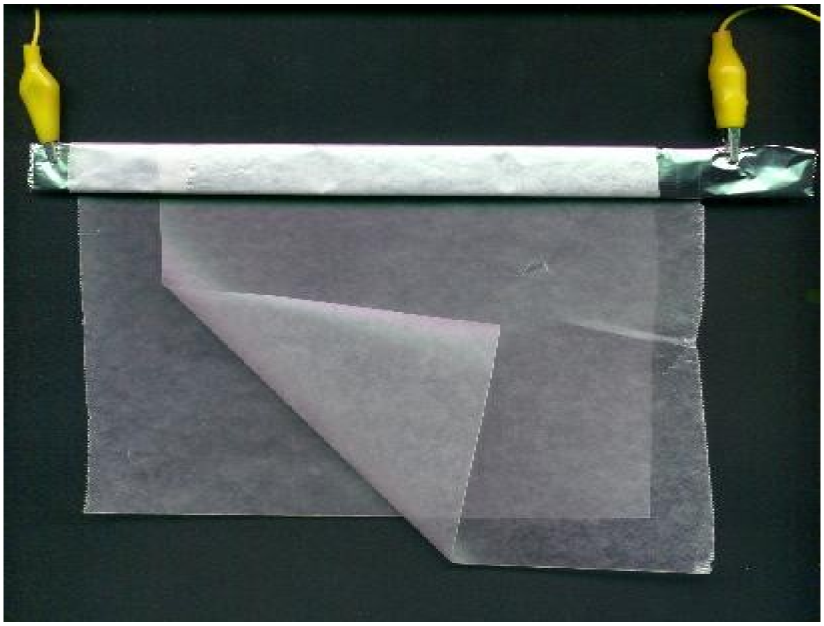
With only a little more effort, we can make a durable, stable, capacitor using foil and a little waxed paper or plastic wrap.

We start by laying down a sheet of waxed paper. On top of that we lay a sheet of foil. We leave the foil hanging over the top of the waxed paper, so we will have something to which we can attach a wire. We lay another piece of waxed paper over the first piece and the foil. We then lay another piece of foil on the top, overlapping it at the bottom for our other wire. We make sure that the foil

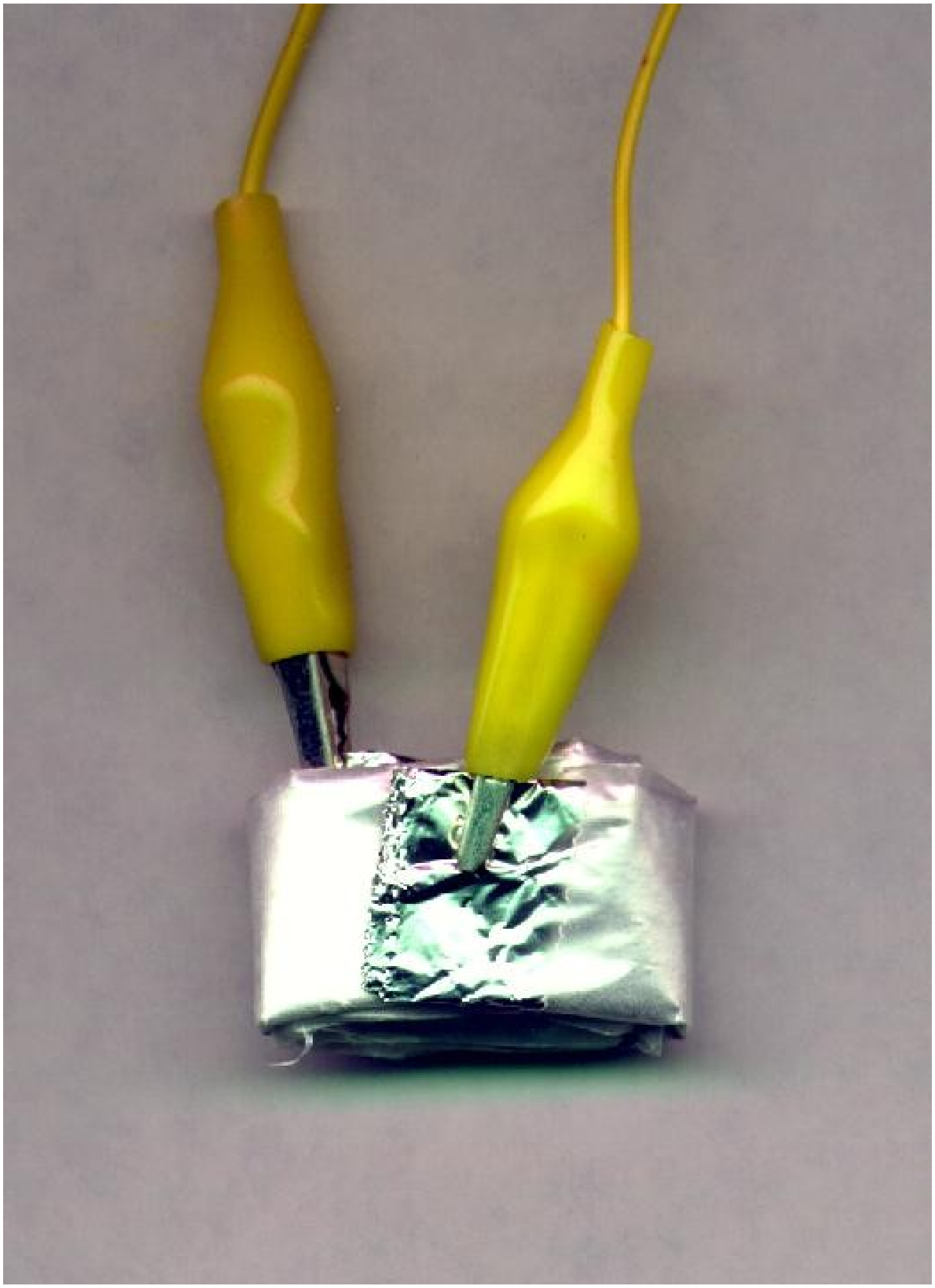
sheets are always separated by the waxed paper, so they do not make an electrical connection.



Now we roll the whole thing up like a jelly roll.



Now we trim up the paper with some scissors, and we can even roll it up the other way to make it smaller.

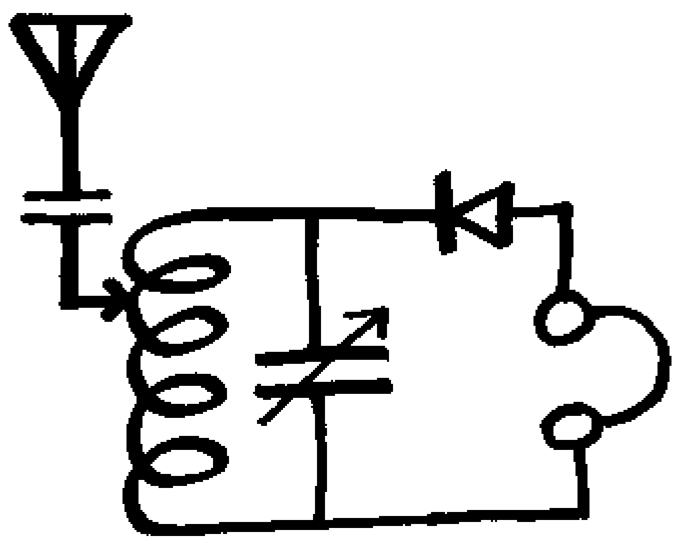


This capacitor is not adjustable like our first one, but we can make several of them, each a different size, and connect the one we want. We can even combine them in

parallel or in series to change their capacitance.

We can use the small *fixed* capacitor to tune the antenna, and another *variable* capacitor (like our book capacitor) to tune the coil. We put the variable capacitor in parallel with the coil, to make a tank circuit. The small fixed capacitor lowers the antenna's capacitance, making the circuit tune to a higher frequency. But the variable capacitor adds more capacitance to the circuit, making it tune to a lower frequency. Now we can tune the radio with the taps on the coil, *and* by sliding the foil in and out of the book.

The circuit now looks like this:



Notice how the variable capacitor has an arrow through it to indicate that it can change its capacitance.

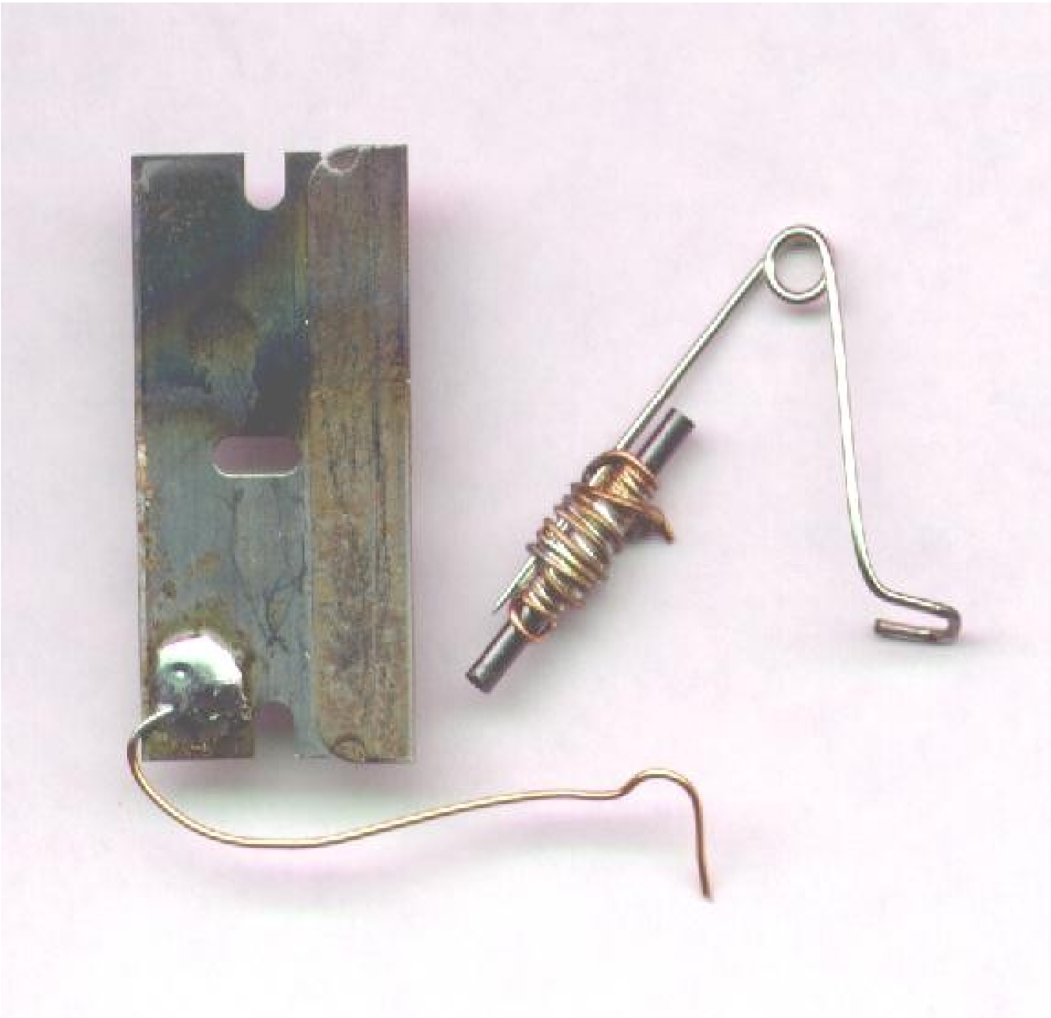
Building your own diodes

During World War I, soldiers in the field made their own radios to listen to programs for entertainment and news. They had access to wire from broken down vehicles, and telephone receivers, but they did not have modern solid state diodes in little glass tubes.

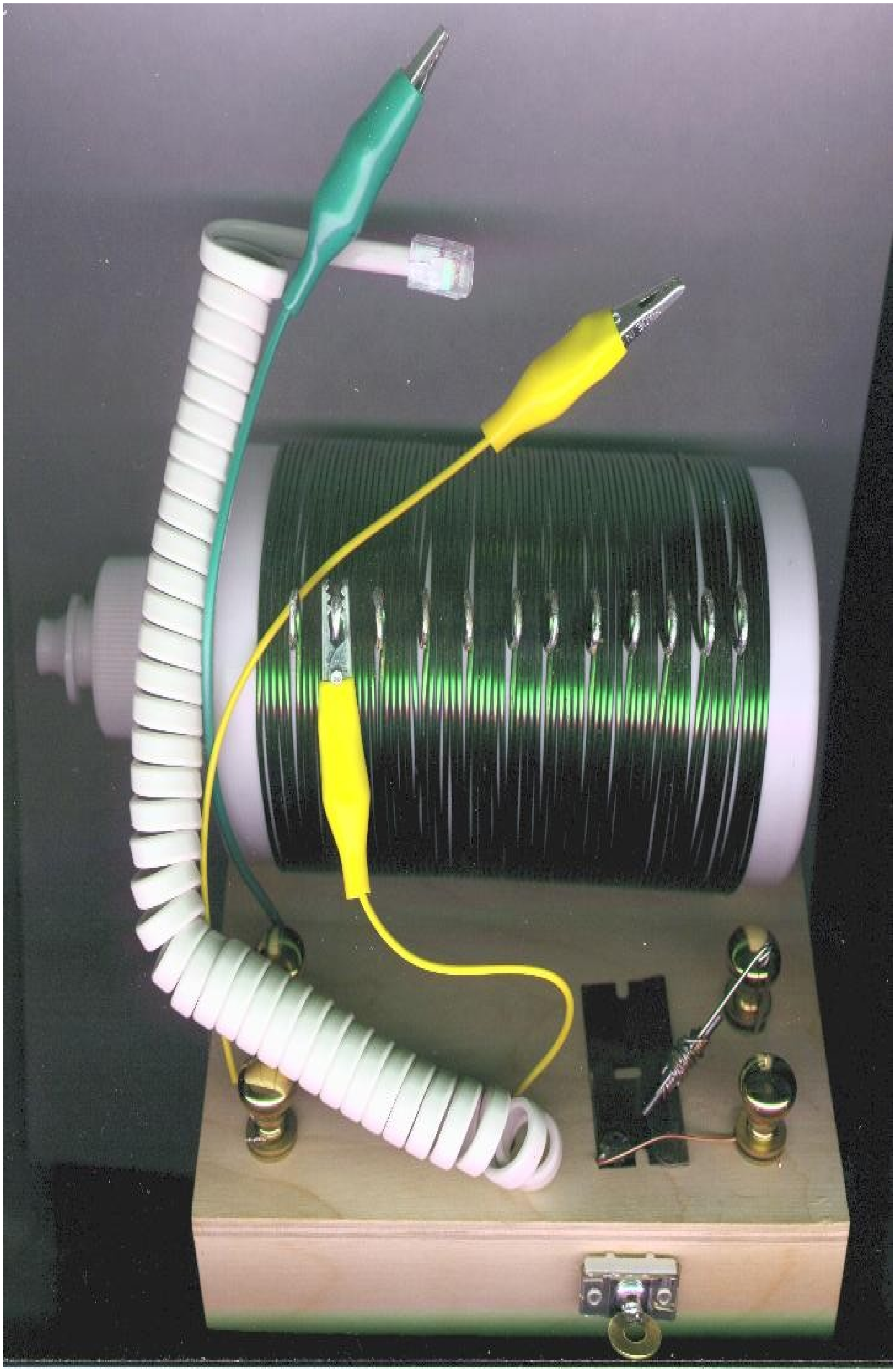
However, it is surprising to find out just how many ordinary objects can act as a diode, letting current flow one way better than another.

The soldiers found that an old rusty razor blade and a pencil lead worked just fine. By lightly touching the pencil lead to spots of blue on the blade, or to spots of rust, they formed what is called a *point contact* diode.

We can replace our store-bought diode with a homemade point contact diode and compare the results. The parts can be attached to the circuit with clip leads, or they can be soldered, as in the photo below. The pencil lead is attached to a safety pin by wrapping it with bare copper wire and soldering it.



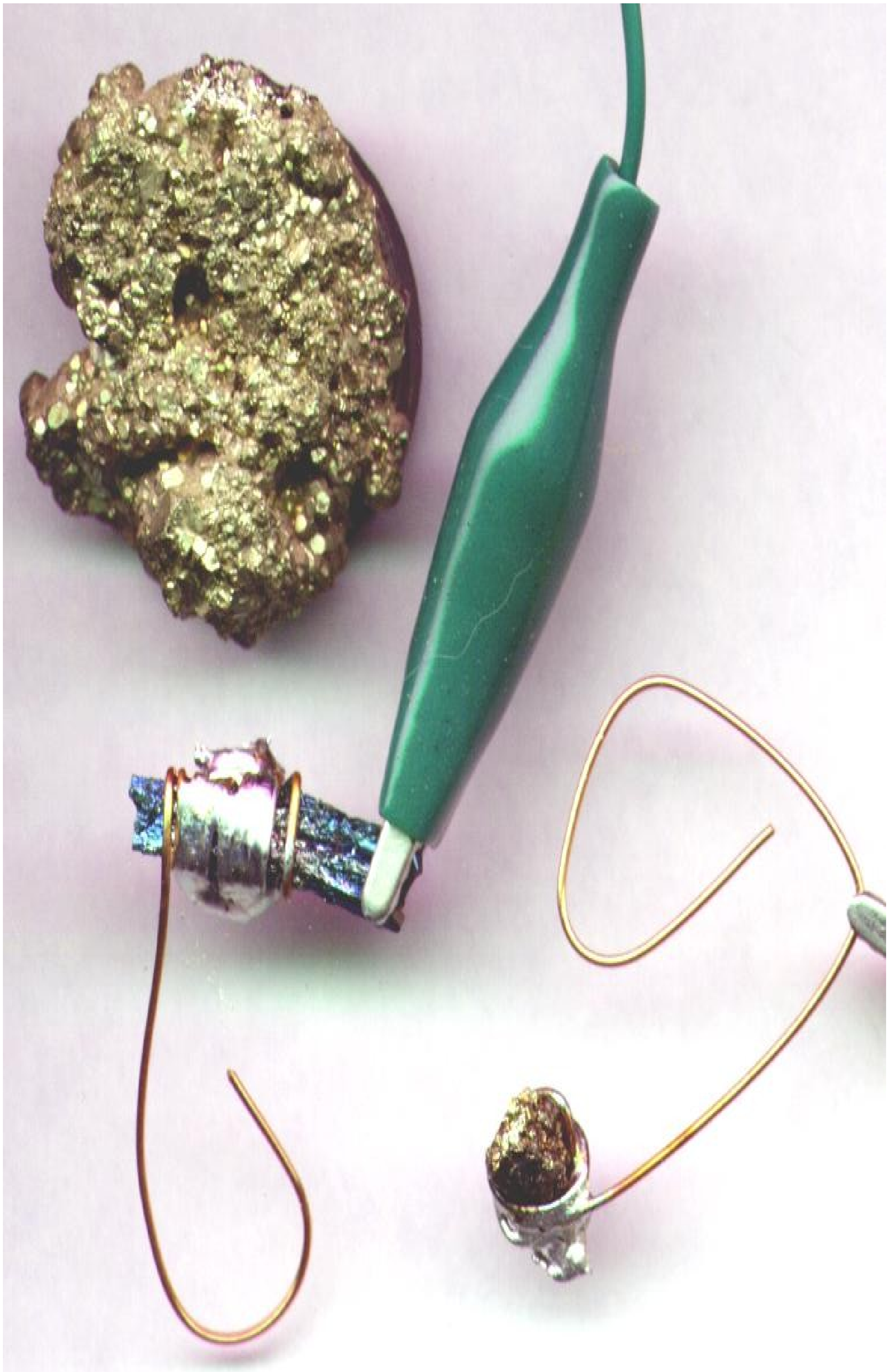
The safety pin acts as a spring to lightly press the pencil lead onto the razor. If the pressure is too hard or not hard enough, the diode will not work, so experiment. The exact spot on the razor is also critical, since some spots will have too much or too little oxide on them to make the diode. Move the pencil lead around on the razor until the sound is loudest, or the meter (if you have attached one) reads highest.



In the photo above, you can see how handy the brass drawer pulls are when we want to attach new types of diodes.

If you don't have a rusty razor blade lying around, you can try other bits of rusty metal. The blade shown above was clean and new, so I put a little salt and water on it, and held it in the flame of a gas stove until parts of it were blue and purple.

You might have other things around the house that can act as diodes. In my rock collection, I found some iron pyrite (fool's gold) and some carborundum (silicon carbide, the blue stone in the photo below). The carborundum works well with a strong pressure, so I simply wrapped some bare copper wire around it, soldered the wire, and then let the jaws of a clip lead supply the pressure. It works quite well. The pyrite needs a gentle touch, so I used the point of a safety pin to gently probe until I found a spot on the pyrite that gave good volume in the radio.



Going further - some quick thoughts

Trading loudness for more stations

In our radio, the diode and earphones are connected directly to the antenna and ground. This connection gets the loudest signal. However, it also *loads* the tuning coil, making it less selective. This means that many lower power or distant stations are drowned out by local strong stations.

We can make the radio more selective by decoupling the tuning coil from the antenna and ground. We do this by adding a small coil. The new coil is attached to the antenna and the ground, and then it is placed inside the main tuning coil.

Wind about five or ten turns of wire around a small coil form such as the plastic container use to package 35 mm film (about 1 inch in diameter). Cut a large hole in the bottom of the plastic bottle on which we wound the large tuning coil. Attach the antenna and ground to the small coil, and place it into the large tuning coil using the new hole you just made. By moving the small coil in or out of the large coil, you can vary the coupling between the coils, and thus vary the selectivity and sensitivity of the radio. If you want loud strong local stations, place it all the way in. If you want to hear the fainter distant stations, pull it out a bit.

Help with construction math

Here is a simple little program that can show you how many turns of wire you need on your tuning coil to resonate with any capacitor you choose:

A coil construction calculator

Building your own earphones

You can build your own earphones using a tin can, a nail, a small magnet, and some fine wire. Wind a few hundred turns of wire around the nail. Let the magnet stick to the head of the nail (a neodymium-iron-boron supermagnet in our catalog works well here, since it is strong and very small). Attach the coil to the radio in place of the earphones. Hold the open end of the tin can to your ear, and hold the nail very close to the bottom of the tin can. The bottom of the can will be attracted to the magnet, but the coil will make it vibrate with the sound from the radio.

A coil from an old relay or solenoid will often also work, and save you the effort of winding the wire on the nail.

A seashell loudspeaker

I got a large conch shell from an aquarium store for a few dollars. Using a concrete drill, I made a 1/4 inch hole in the shell at the small end (where the shell was formed when the conch was very small). I then glued a piezo-electric earphone to the hole. This makes a nice trumpet-

like megaphone and makes the sound of the radio clearly audible across a quiet room. It also looks very nice.

Using an LED for a diode.

Because I have a long (150 foot) antenna, a good ground, and a strong station (50,000 watts) less than 20 miles away, my radio receives enough power to light a low current LED. The LED is a 'high brighness' type (which also means that it will light dimly with a very small amount of current). I connect it instead of diode in the radio, and it glows as the radio operates, getting brighter as the sound gets louder.

If you don't have a strong station nearby, you can add a battery in series with the LED (a small 1.5 volt battery works fine). The LED will light up, and the radio will play much louder than without the battery (if the LED doesn't light up, try connecting the battery the other way around). This arrangement is the best detector I have used so far, and is louder than the 1N34A germanium diode.

Next: A simple radio transmitter

Sources for crystal radio parts

All Electronics

High impedance earphones

Variable capacitors P.O. Box 567
Van Nuys, CA 91408-0567
Phone: 1-800-826-5432
Fax: 1-818-781-2653
eMail: allcorp@allcorp.com

Halted Specialties Corporation (HSC Electronic Supply)

High impedance earphones

Variable capacitors 3500 Ryder Street
Santa Clara, CA 95051.
Phone: (408) 732-1573
Fax: (408) 732-6428
eMail: hscmail@halted.com

Haltek Electronics

High impedance earphones 1062 Linda Vista Ave.
Mountain View, CA
Phone: (415) 969-0510

RA Enterprises

High impedance earphones

Variable capacitors 2260 De La Cruz Blvd
Santa Clara, CA
Phone: (408) 986-8286

Alltronics

High impedance earphones

Variable capacitors 2300-D Zanker Road
San Jose, California 95131
Phone: (408) 943-9773
Fax: (408) 943-9776
eMail: ejohnson@alltronics.com

Electronic Goldmine

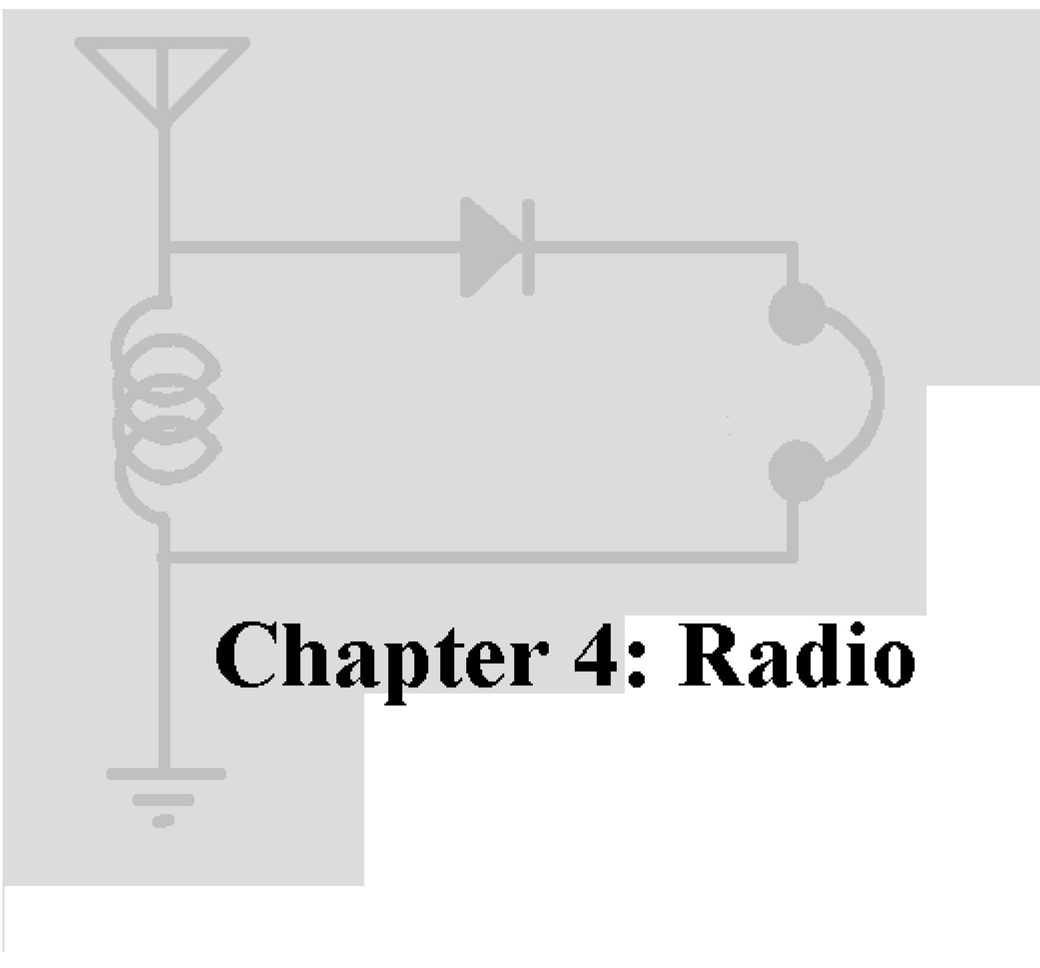
High impedance earphones

Variable capacitors P.O. Box 5408

Scottsdale AZ 85261 Phone: (602) 451-7454
Fax: (602) 661-8259
Toll Free Order Line: (800) 445-0697

Edmund Scientific

Crystal radio kits with piezoelectric earphones Consumer Scientific Division
Dept. 16A1, C911 Edscorp Bldg.
Barrington, NJ 08007
Phone: 609-547-8880
Fax: 609-547-6295
toll free: 1-800-728-6999
eMail: scientifics@edsci.com

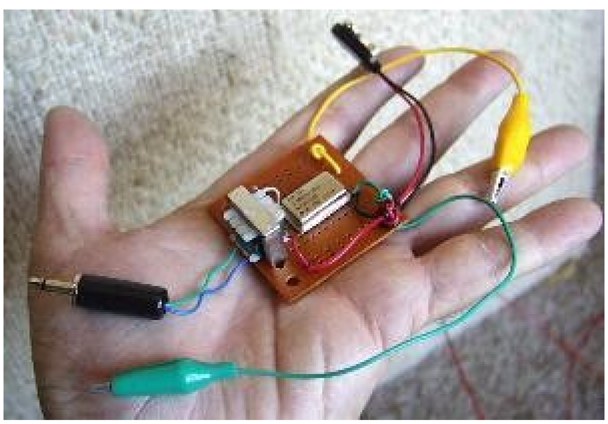


Chapter 4: Radio

Building a very simple AM voice transmitter

If a crystal radio is the distilled essence of a radio, this transmitter is the matching distilled essence of transmitters.

The transmitter goes together in about 10 minutes, and is small enough to fit in the palm of your hand.



Click on photo for a larger view

Depending on the antenna, the transmitter can send voice and music across the room, or across the street.

I put together my first version with simple clip leads (no soldering, no printed circuit board, not even a battery clip). This version is much sturdier and convenient.

An AM transmitter from simple parts

Our transmitter will need these parts:

- A one megahertz crystal oscillator

  This is a crystal clock oscillator such as those used in computers. There are many suppliers, such as

  Jameco (part #27861) or
  JDR MicroDevices part OSC1.0

  We also carry this item in our catalog.

- An audio transformer

  This is a 1000 ohm to 8 ohm audio transformer, such as Radio Shack #273-1380.

  We also carry this item in our catalog.

- A generic printed circuit board

  I used Radio Shack's #276-159A, but any general purpose printed circuit board will do.

- A phone plug

  This should match the jack in your sound source. I use a 1/8 inch (Radio Shack #274-286A) plug to match standard earphone jacks of transistor radios and Radio Shack's Archer mini-amplifier speaker.

- A 9 volt battery clip

  I like the Radio Shack heavy duty type, part number 270-324.

- A 9 volt battery
- A set of alligator jumpers.

  Radio Shack part number 278-1156, or you can find them anywhere electronics parts are sold.

- Some insulated wire for an antenna.

  You can use the same antenna you used for the crystal radio.

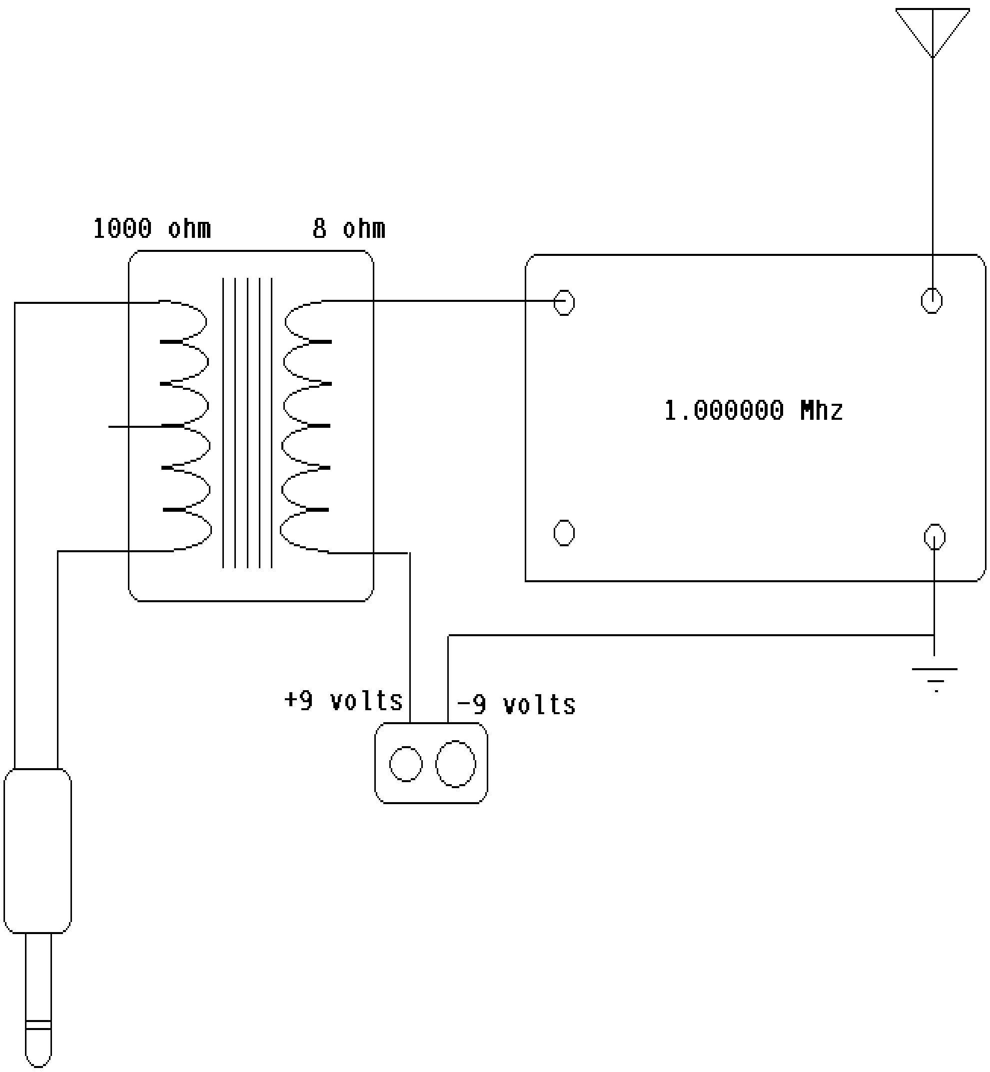
Building the transmitter

The oscillator is the heart of the transmitter. It has four leads, but we only use three of them. When the power is connected to two of the leads, the voltage on third lead starts jumping between 0 volts and 5 volts, one million times each second.

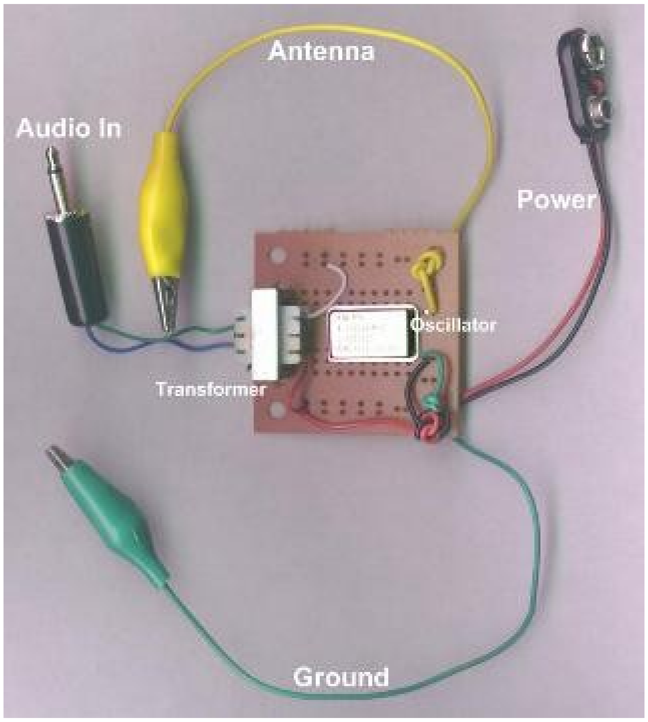
The oscillator is built into a metal can. The corners of the can are rounded, except for the lower left corner, which is sharp. This indicates the where the unused lead is. The lead is there to help hold the can down firmly on the printed circuit board, but it is not connected to anything inside the can.

The other main part is the audio transformer . In this circuit it is used as a *modulator*. The modulator changes the strength of the radio waves to match the loudness of the music or voice we want to transmit.

A pictorial diagram of the transmitter looks like this:



A photograph of the completed transmitter is shown below:



Click on photo for a larger view

The transformer has two leads on one side, (red and white in the photo) and three leads on the other side (blue, black and green in the photo). The two leads are the *low impedance* side of the transformer, (the 8 ohm side). The three leads are the *high impedance* side (the 1000 ohm side). The middle of the three leads is called the *center tap*, and we won't be using it in this circuit.

Putting it together

The transformer has two metal tabs on the bottom. These can be bent out flat, so the transformer can be glued to the printed circuit board, or two holes can be drilled in the board, and the tabs can fit into the holes and be folded over to hold the transformer in place. If you choose to drill the holes and fold over the tabs, the tabs can be soldered to the copper pads on the back of the printed circuit board for a more secure anchor.

The transformer should be placed on the left side of the printed circuit board, leaving plenty of room on the right for the oscillator.

Insert the leads of the oscillator into the printed circuit board, placing it far to the right. The copper side of the board should be down, with the oscillator on the side without copper.

Gently bend the leads of the oscillator over, so it is held firmly onto the printed circuit board.

Solder the pins of the oscillator to the copper foil of the printed circuit board. Be careful not to use too much solder, or it may form bridges of solder between copper traces that are not supposed to be connected together.

Insert the stripped end of the red wire into a convenient unused hole in the printed circuit board (such as the bottom left hole). Insert the red wire from the battery clip into a nearby hole that is connected by copper foil to the first hole, so the two red wires are electrically connected. Solder the two wires to the copper foil.

Insert the white transformer wire into a hole whose copper foil is connected to the upper left pin of the oscillator. Solder this wire to its copper foil.

Cut one of the clip leads in half, so you have two pieces of wire each with an aligator clip attached. In the photo, I used two different colors for clarity (yellow and green). Strip the insulation from the last half inch of each piece.

Insert the black wire of the battery clip into a hole whose copper foil connects to the lower right pin of the oscillator. Insert the stripped end of one of the aligator clip leads into a hole that is also connected to the lower right pin of the oscillator. Solder the two wires to the copper foil. The aligator clip will be the *ground* connection, just like in the crystal radio.

Insert the stripped end of the other aligator clip into a hole that is connected to the top right pin of the oscillator. Solder the wire to the copper foil. This will be the antenna connector.

Open the phone plug, and insert the blue and green wires of the transformer into the plastic handle. The metal part of the plug has two pieces, each with a small hole. Put one of the transformer wires into one hole and solder it, then put the other wire into the other hole and solder it. When the metal has cooled, screw the plastic handle back onto the metal phone plug.

Using the transmitter

We are now ready to test the transmitter.

Plug the phone plug into the earphone jack of a convenient sound source, such as a transistor radio, tape player, or CD player.

Plug the batter into the batter clip.

Hold the transmitter near an AM radio, and tune the radio to 1000, so you can hear the your sound source in the AM radio. Adjust the volume controls on the sound source and on the AM radio to get the best sound.

Without any connection to an antenna or a good ground connection, the transmitter will only transmit to a receiver a few inches away. To get better range, clip the ground wire to a good ground, such as a cold water pipe, and the antenna to a long wire, like the one we used for the crystal radio. Many countries limit the length of the antenna you are allowed to use without a license, so

check with your local laws before using a wire more than a yard or two long.

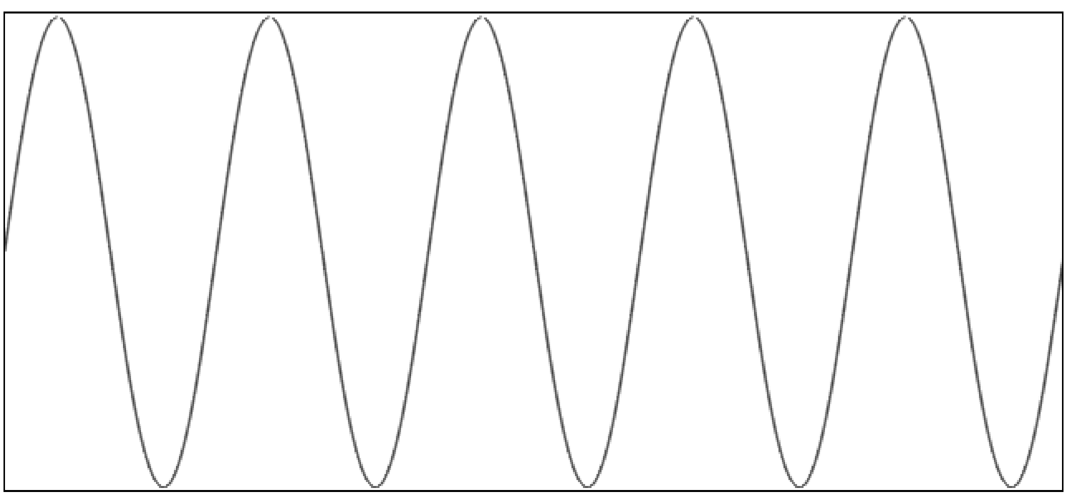
For a science fair project, the transmitter and receiver can be placed within a few feet of one another, and a short wire antenna should be just fine.

How does it do that?

The oscillator is connected to one end of a long wire antenna. It alternately applies 9 volts of electricity to the end of the wire, and then 0 volts, over and over again, a million times each second.

The electric charge travels up and down the wire antenna, causing radio waves to be emitted from the wire. These radio waves are picked up by the AM radio, amplified, and used to make the speaker cone move back and forth, creating sound.

The sound source (your CD player, or tape recorder) is normally connected to drive a speaker or earphone. It drives the speaker by emitting electricity that goes up and down in power to match the up and down pressure of the sound waves that were recorded. This moves the speaker in and out, recreating the sound waves by pushing the air in and out of your ears.

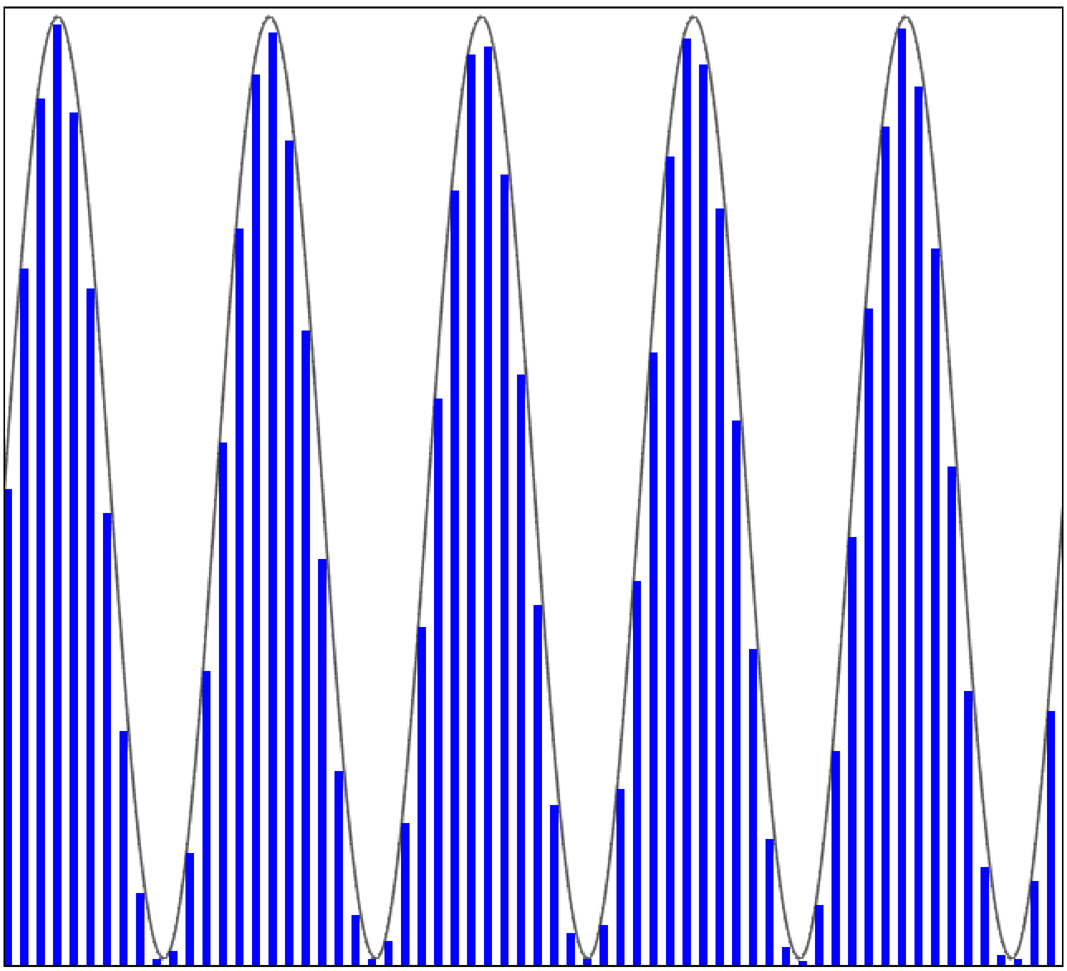


Sound waves

In our transmitter, the sound source is connected to the transformer instead of to a speaker.

The transformer is connected to the power supply of the oscillator. The sound source causes the transformer to add and subtract power from the oscillator, just as it would have pushed and pulled on the speaker.

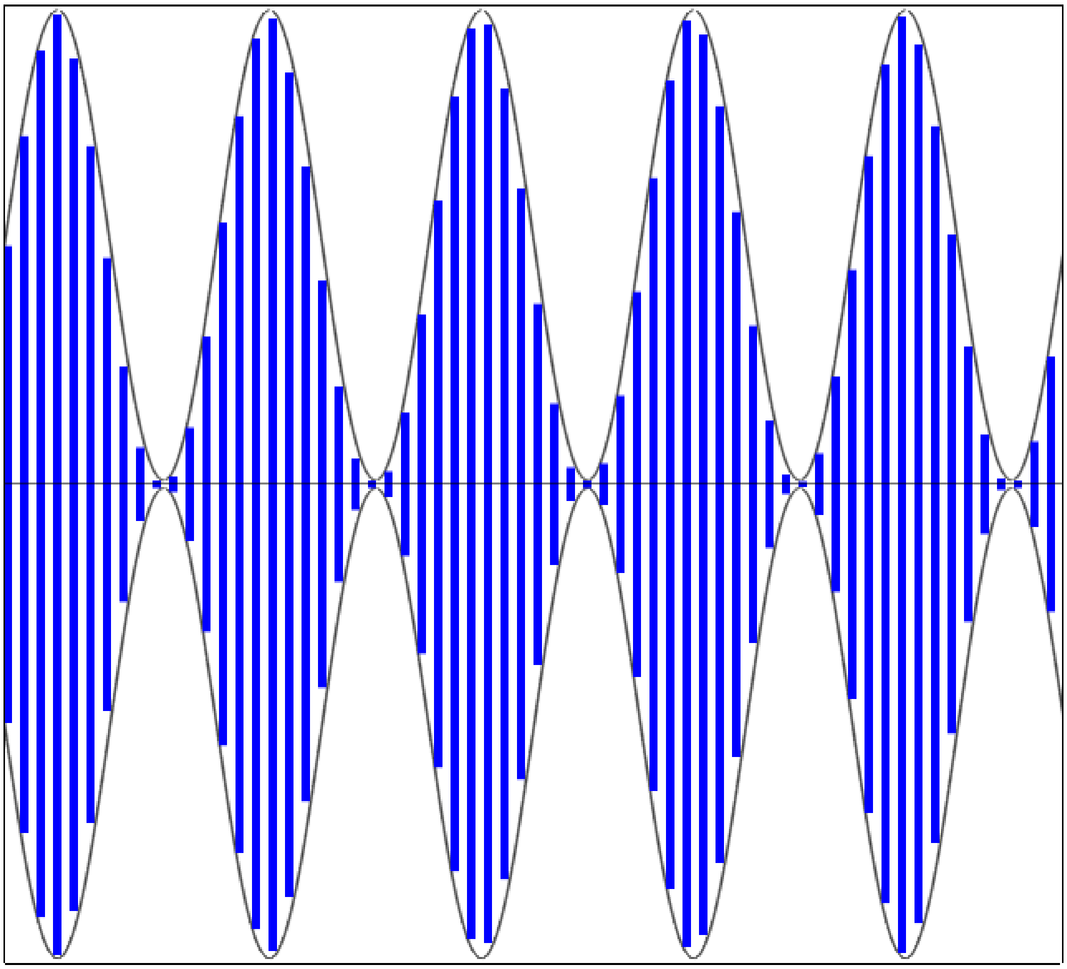
As the power to the oscillator goes up and down, the power of the electricity in the antenna goes up and down also. The voltage is no longer simply 9 volts. It is now varying between 0 volts and 10 volts, because the power from the transformer adds and subtracts from the power of the battery.



Power into antenna

The varying power in the antenna causes radio waves to be emitted. The radio waves follow the same curves as the waves in the antenna. However, because the transmitter and the receiver are not connected, the receiver does not know what the transmitter is

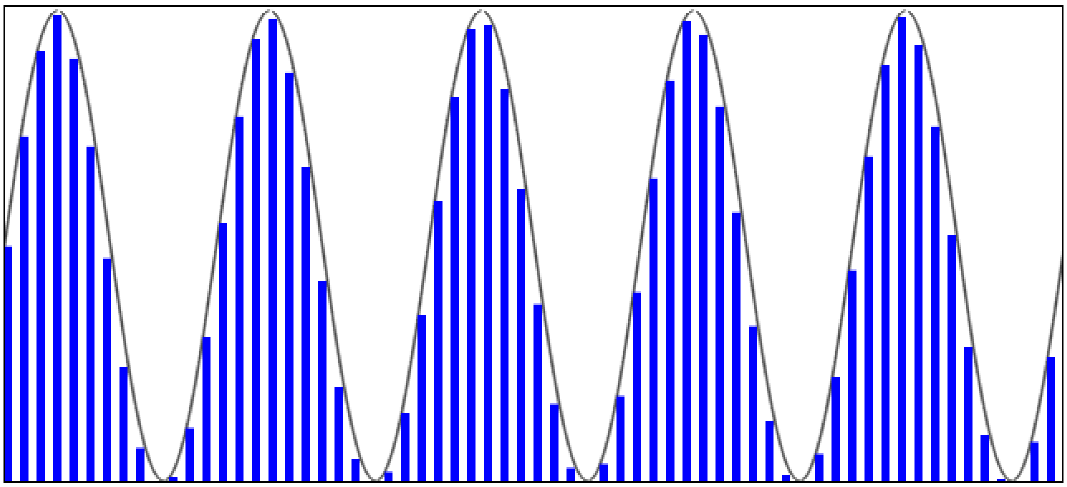
using for the value of zero. All the receiver sees is a radio wave whose amplitude is varying. In the receiver, zero is the average power of the wave. This makes the wave look like this:



Radio waves in free space

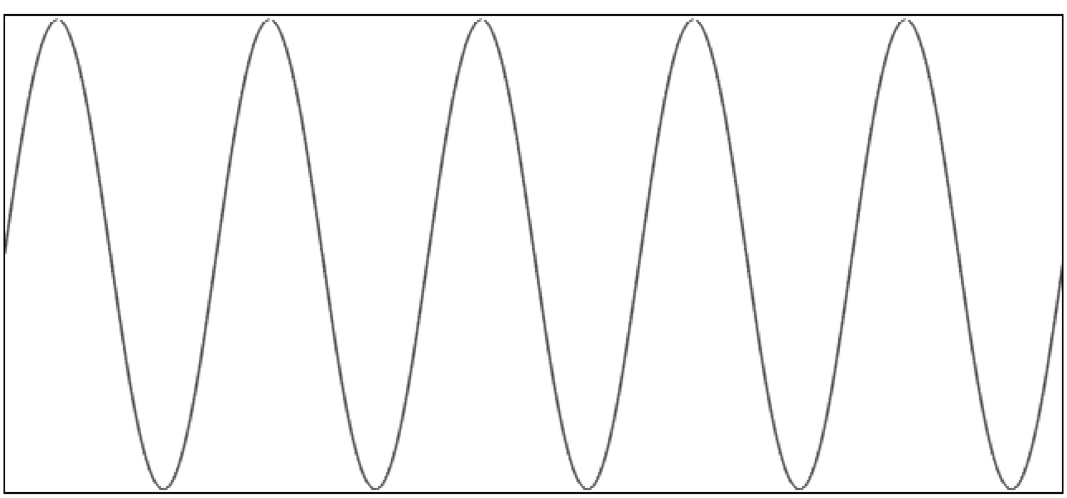
If we sent this wave to the earphone, we would hear nothing, because the average power is zero. This is why our crystal radio has a diode.

The diode does a neat little trick. A diode only lets electricity flow in one direction. This means that the part of the graph where the power is rising *up* from zero can get through the diode, but the part where the power is going *down* from zero is blocked.



Electrical signal after the diode

All those little peaks of power happening a million times per second are too fast for human ears, and too fast for the earphone to reproduce. But since they are all pushing on the earphone diaphragm, all those little pushes add up, and the earphone moves. Since some of the little pushes are stronger than others (taller blue bars in the illustration) they move the earphone more than the weaker ones. We hear this variation as sound.

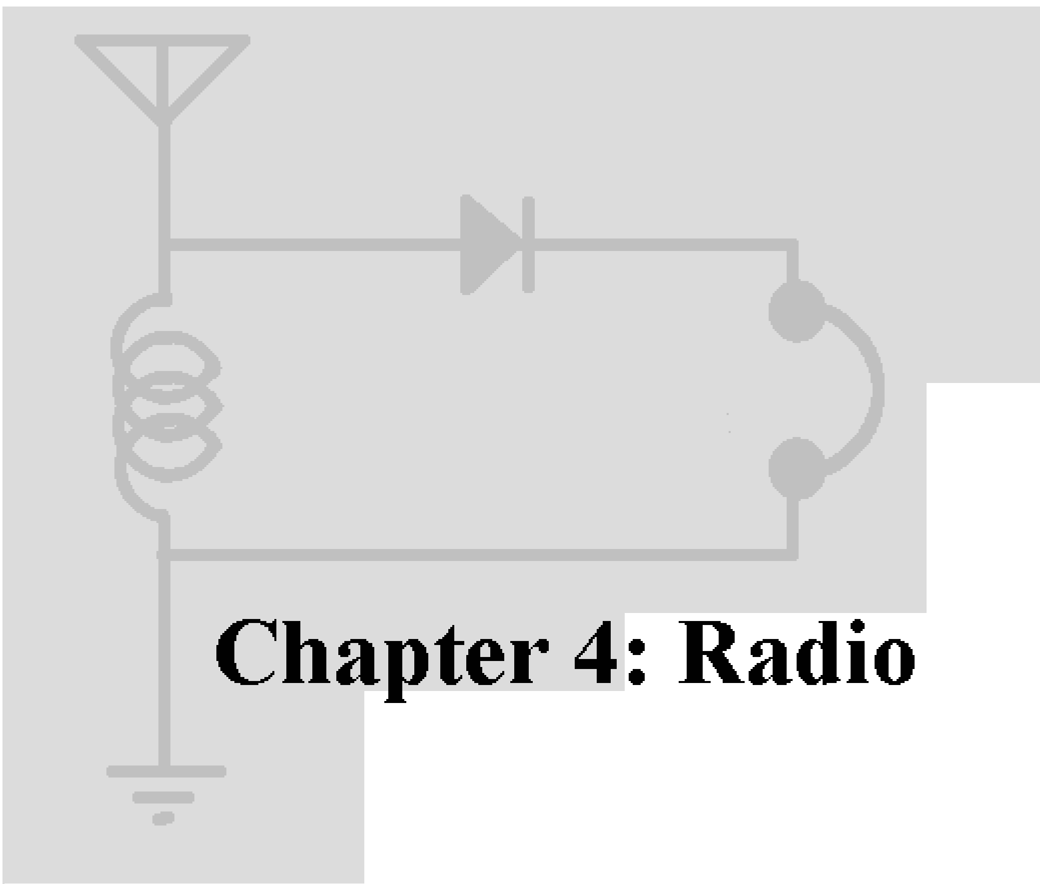


Sound waves reaching our ears

The sound is a faithful reproduction of the original sound wave at the transmitter.

For more information on radio, see the Recommended Reading section.

Next: Building the Three-Penny Radio



Chapter 4: Radio

Building a simple crystal radio.
Building a radio in ten minutes.

Building a Three-Penny Radio.

A crystal radio is nice because it needs no power, and the materials can all be home-made or at least found around the house. But the crystal radio needs a big antenna, and a good ground, and so is not very portable.

To get away with using a much smaller, portable antenna, we will need to amplify the tiny signal it receives. This requires a portable power supply, such as a battery.

Our next toy is a portable radio. It can be powered from a tiny 1.5 volt battery, or from a battery made from copper wire and aluminum foil sitting in a glass of lemonade, a soft drink, or a beer, or by a few small commercial solar cells.

The heart of the radio is a special 10 transistor integrated circuit in a tiny three-legged bit of plastic. This circuit comes ready-made with several amplifiers, the detector, and an Automatic Gain Control circuit that boosts the level of faint stations to match the strong ones, so no volume control is needed. The final radio has excellent performance, pulling in weak stations, and preventing nearby strong stations from overwhelming the weak ones next to them on the dial.

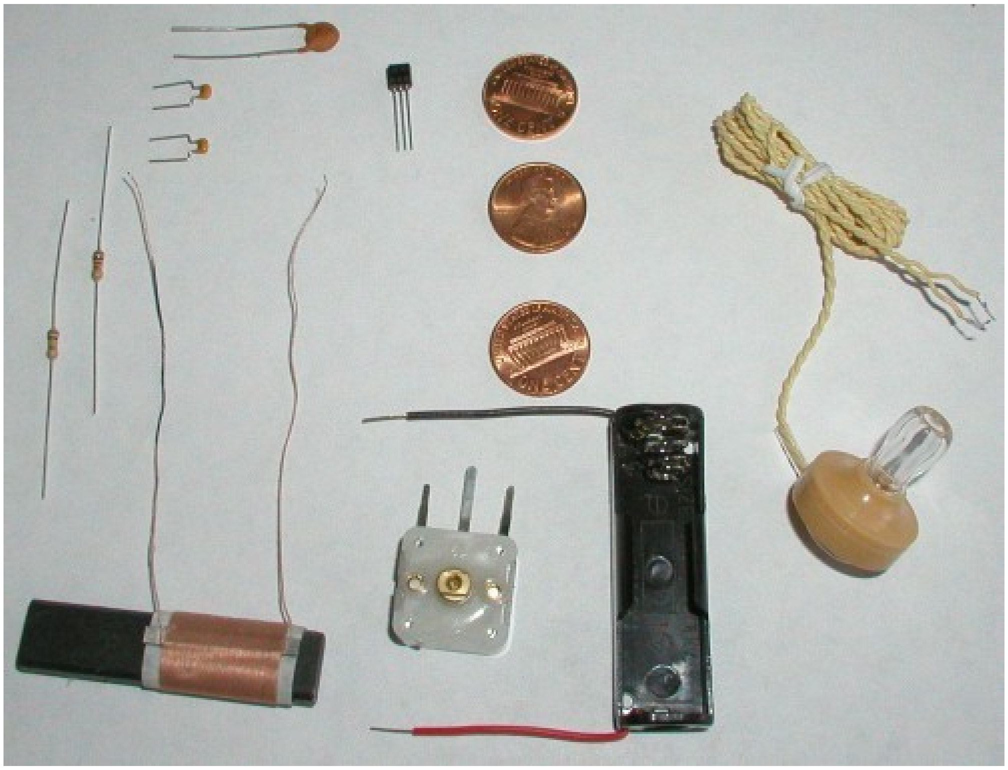
We call the radio a "Three Penny" radio because we use three shiny pennies as anchors for the various parts the radio needs. This makes the construction very easy.

If you have never soldered anything before, this is a great project to start with. It is very forgiving of the type of soldering usually done

by beginners, and all the parts are widely separated, making the job much easier than with other circuits. Soldering irons and solder are inexpensive tools you can find at a local electronics store such as Radio Shack.

The three-penny radio needs these parts: (We carry a bundle of all the necessary parts in our catalog.)

- **Three shiny pennies** You can clean them up with polish, or you can use brand new ones.
- **A tuning coil** You can wind one by hand, but in this project we use a much smaller coil with a ferrite rod inside, from our catalog. The coil in the photos has only two wires. The one we ship in the catalog is the improved coil with four wires that we used in the 10 minute radio.
- **An MK484-1 AM Radio Integrated Circuit** This is the heart of the radio. We carry it in our catalog.
- **A Piezoelectric earphone** Also in our catalog.
- **A tuning capacitor** We use a variable capacitor, from 0 to 160 picofarads. We have it in our catalog.
- **A 100,000 ohm resistor** This resistor will have four colored bands on it. The colors will be brown, black, yellow, and gold.
- **A 1,000 ohm resistor** This resistor will also have four colored bands on it. The colors will be brown, black, red, and gold.
- **A 0.01 microfarad capacitor** This capacitor will be marked something like ".01M" or "103".
- **Two 0.1 microfarad capacitors** These capacitors will be marked something like ".1M" or "104".
- **A 1.5 volt battery**
- **(optional) A 1.5 volt battery holder**
-



Click on photo for a larger picture

We start by placing the three shiny pennies on an old board where we will work. An old board will not be missed if a hot soldering iron burns a black spot in it. Don't work on a nice tabletop.

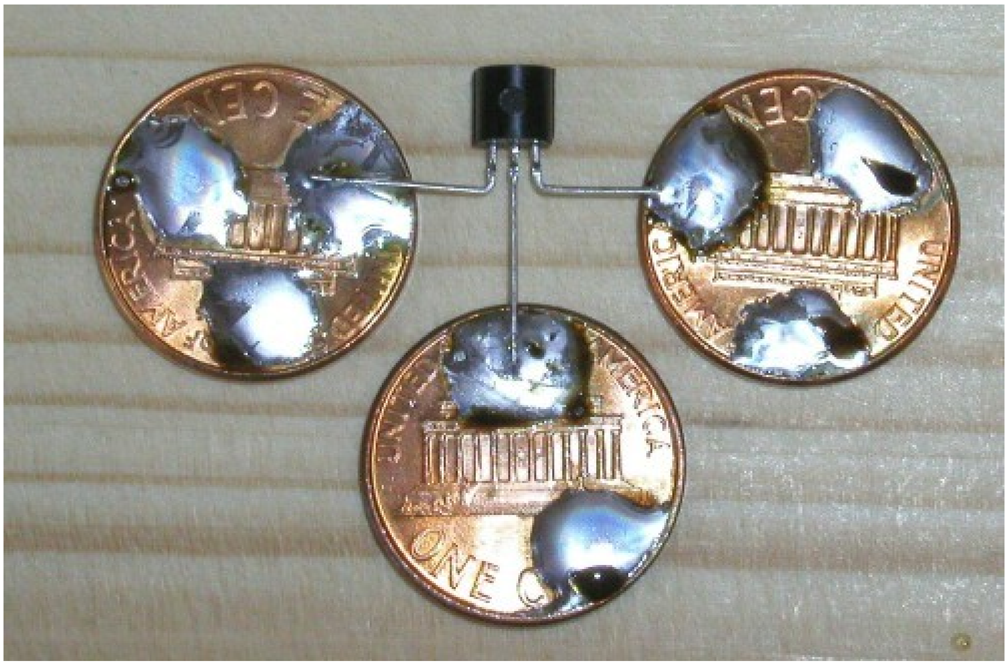
The pennies should be clean and bright. This will help the solder stick to them and flow onto their surface. Solder will not stick to a dirty penny. I used clean relatively new pennies that I didn't have to clean or polish. Old pennies can be cleaned with brass polish or by simply leaving them in a mixture of vinegar and salt for a half-hour or so.

We are going to build the radio "upside-down", so that all of our soldering will be neatly hidden from view when we turn the radio over when we are finished. Select which side of the penny you want to be visible, and place that side face down. I chose "heads" to be visible, so the "tails" side is facing up in the next photo.

The first thing we will do is bend the wires of the integrated circuit so the outside wires stick out like the arms of a scarecrow. This makes the soldering much easier, since the wires are not close together.

The integrated circuit has a flat side and a rounded side. The flat

side will face up when we are done, so we make it face down while we build our radio upside-down. The orientation of this part is important. The three legs are the "output", the "input" and the "ground" when it is upside-down like this. (When face up, the "ground" will be on the left, and the "output" will be on the right.) If the integrated circuit is not flat-side-down at this point, then we won't be connecting to the right parts when we are done, and the radio won't work.



Click on photo for a larger picture

It usually takes a while to heat up a penny enough to melt solder onto it. Hold the soldering iron firmly on the spot on the penny where we want the solder to be, and feed the wire solder onto the hot penny as it melts. It doesn't take much solder. It is often a good idea to make a small blob of solder on the penny first, and then place the wire of the integrated circuit onto the blob of solder, and reheat both until the solder wets the wire.

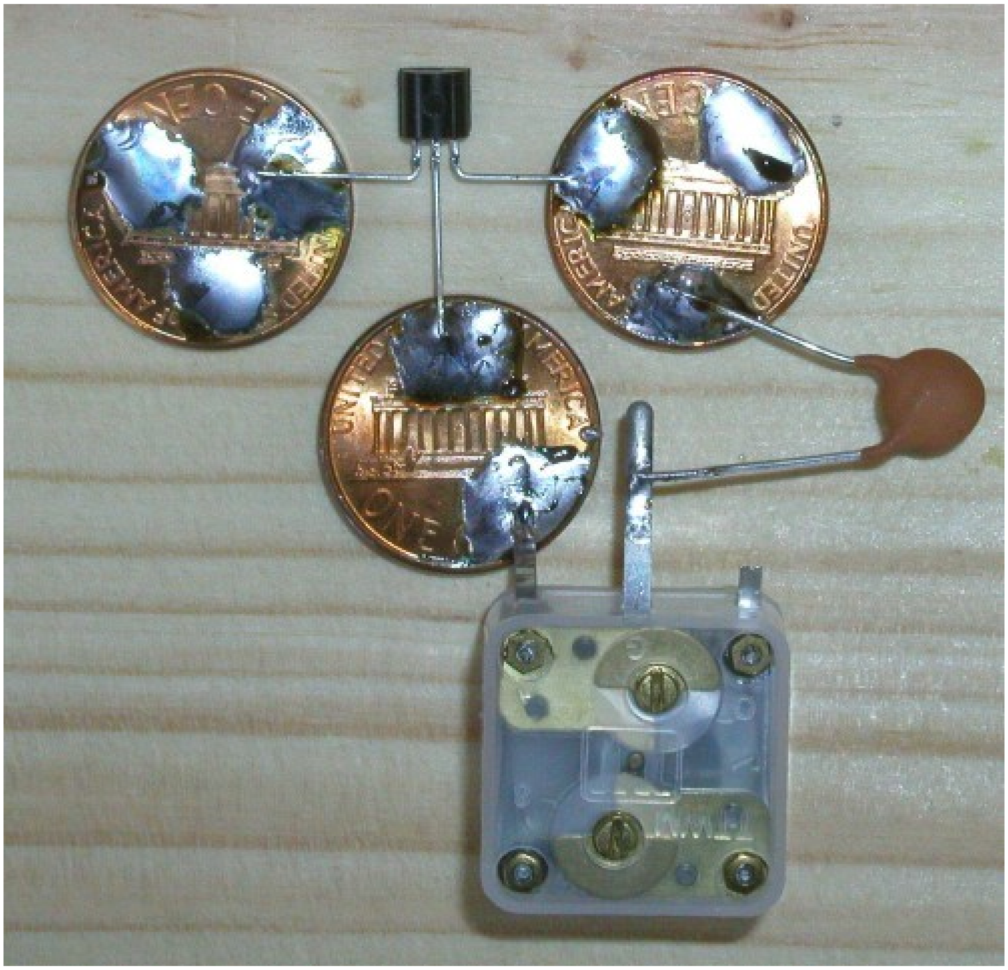
You will see that we have done just that in the photo. The two top pennies have three blobs of solder on them, and the bottom penny has two blobs of solder.

Solder all three of the wires to the three pennies.

Click on photo for a larger picture

The next step is to solder the variable capacitor to the bottom penny. Remember to place the variable capacitor upside down. The variable capacitor has three legs, but we will only be using two of them. This variable capacitor is actually two capacitors in one, and they share the middle leg.

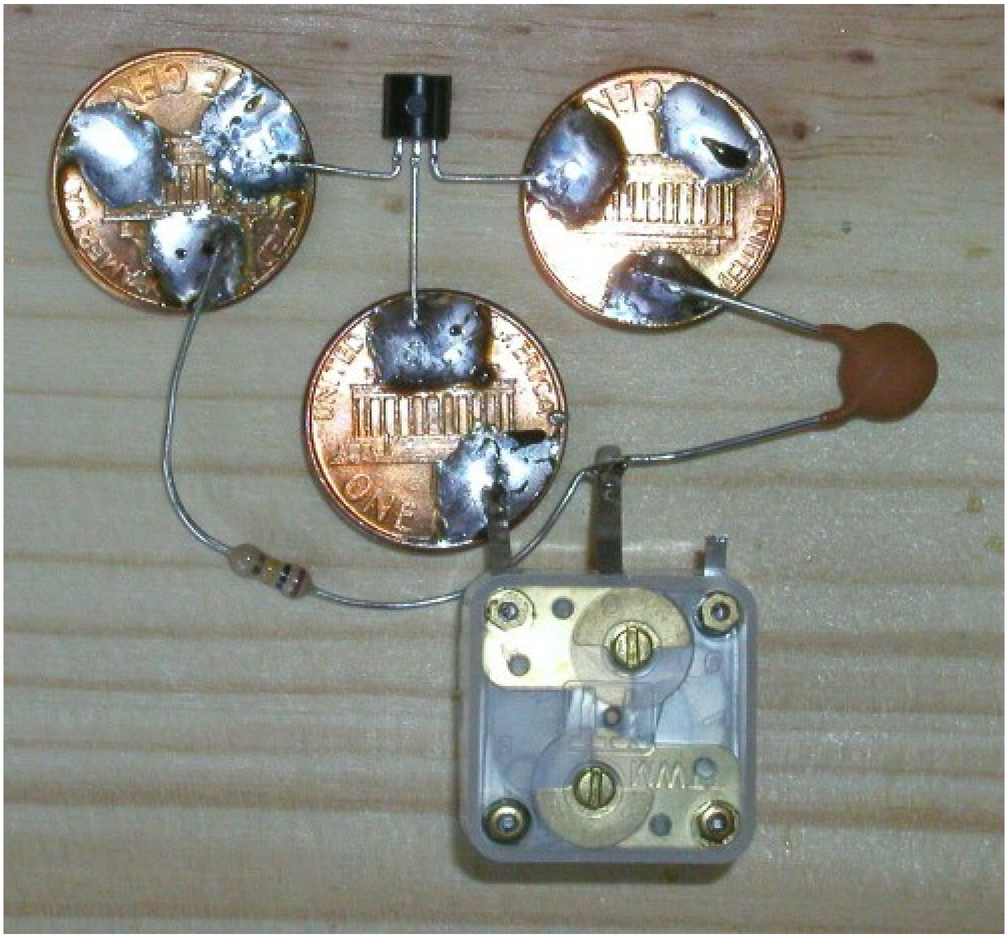
We will only be using one of the capacitors. The two capacitors have different values, and we are using the 160 picofarad side (the left in the photo) and leaving the 60 picofarad side unconnected. As the photo shows, I have cut off the third leg to remind me which side to use.



Click on photo for a larger picture

The next part we add to the circuit is the small fixed value capacitor, the one marked ".01M" or "103". Both of these markings mean the same thing -- the capacitor has the value 0.01 microfarads (we can also say 10 nanofarads, but the tendency in the industry is to use microfarads).

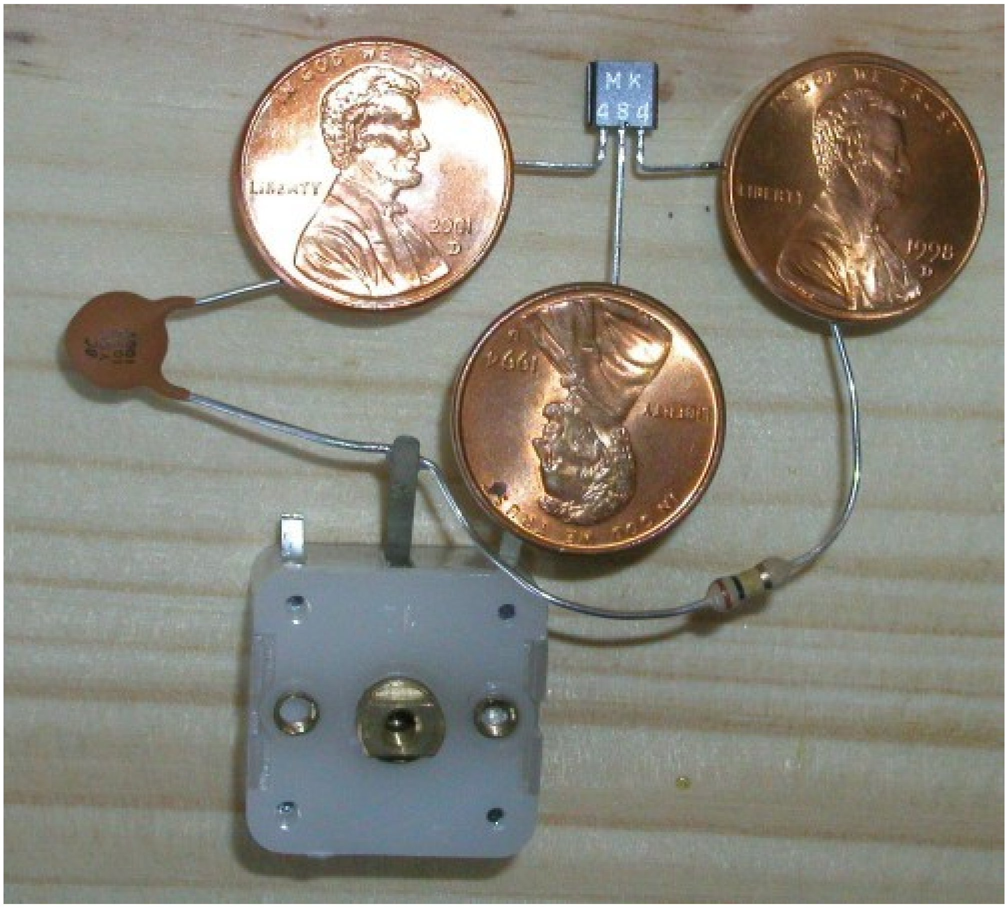
The small capacitor is soldered to the middle leg of the variable capacitor, and to the penny. It is probably easiest to solder it to the penny first, and then to bend it so the other leg touches the middle leg of the variable capacitor, and then solder them where they touch. Always make sure metal parts to be soldered are touching before you solder them -- this makes a stronger joint.



Click on photo for a larger picture

The next part is the 100,000 ohm resistor. In the photo, you can see the color coded bands on it. They are brown, black, yellow, and gold.

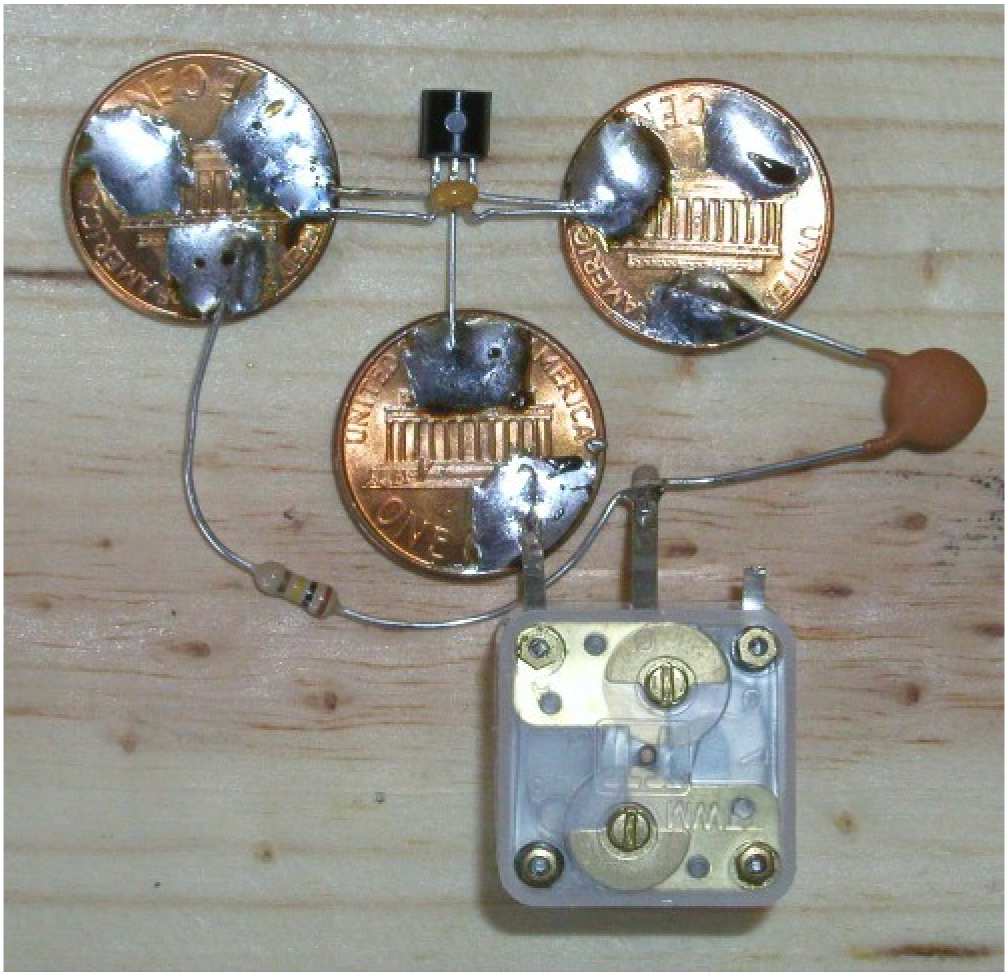
This resistor must be soldered to the middle leg of the variable capacitor at one end, and to the top left penny at the other end. It *must not* touch any other metal part along the way.



Click on photo for a larger picture

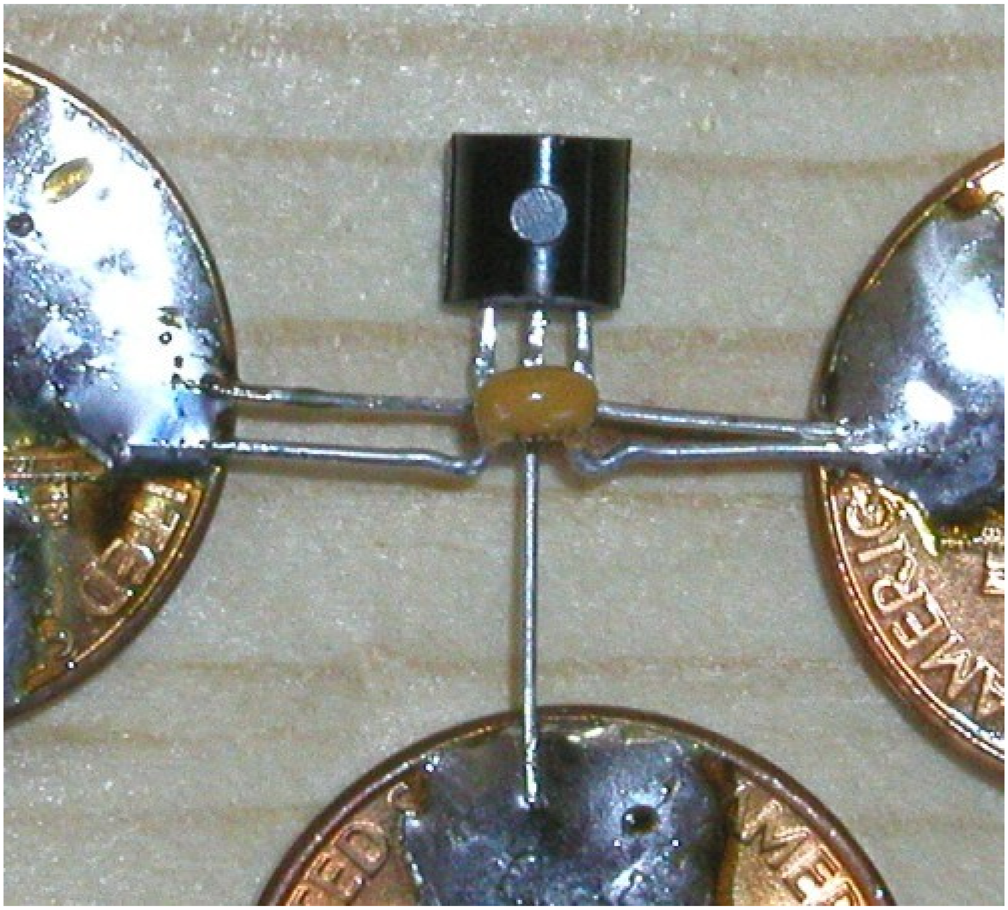
In the photo above, we have turned the project over for a moment to show that the resistor is not touching anything except where it is soldered.

Now we solder the 0.1 microfarad capacitor to the two top pennies. This capacitor will be marked "104", or sometimes "0.1M". If the leads are short, the capacitor can be stretched across the integrated circuit as shown in the photos above and below.



Click on photo for a larger picture

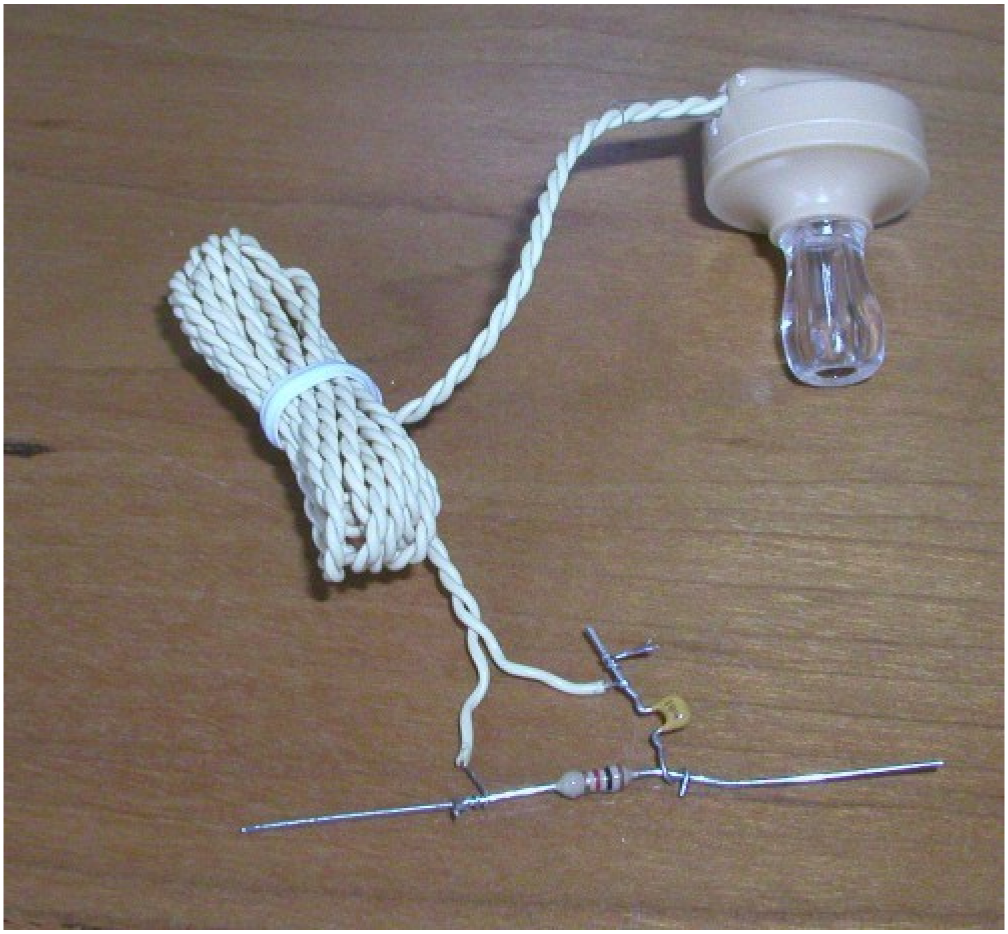
If the leads are long, the capacitor can be placed above the integrated circuit. Make sure the wires from the capacitor do not touch the middle wire of the integrated circuit.



Click on photo for a larger picture

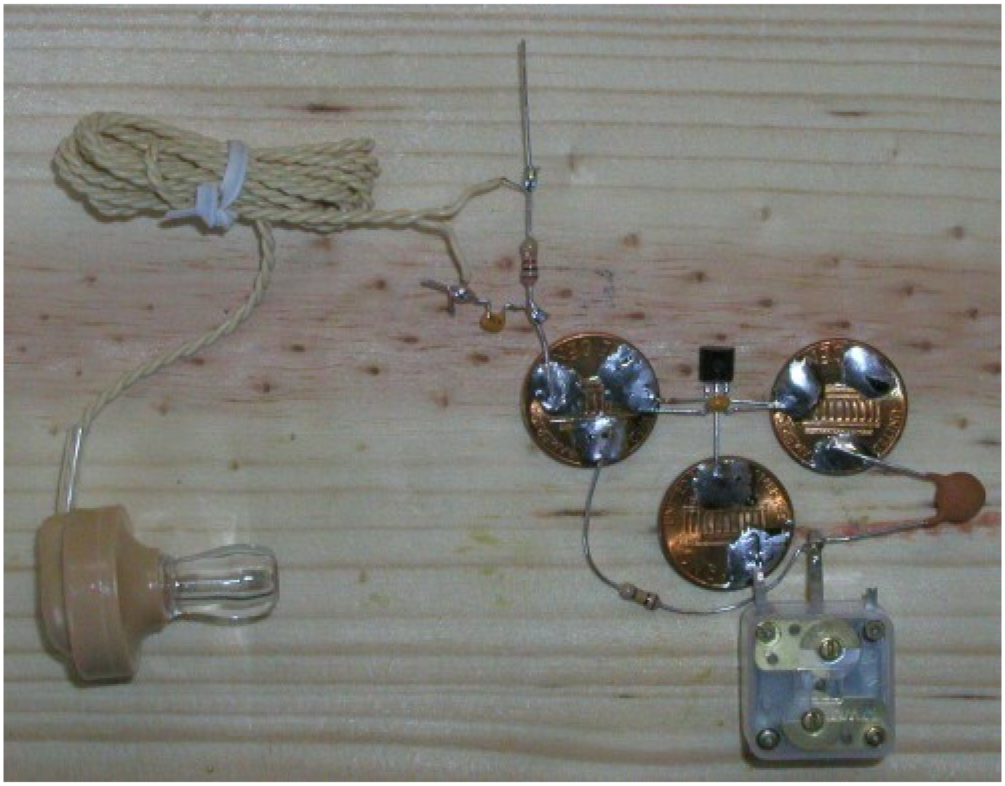
Next we will connect the wires from the piezoelectric earphone to the 1,000 ohm resistor, and to the other 0.1 microfarad capacitor.

The color codes on the 1,000 ohm resistor are brown, black, red, and gold.



Click on photo for a larger picture

Now we solder the resistor to the top left penny.

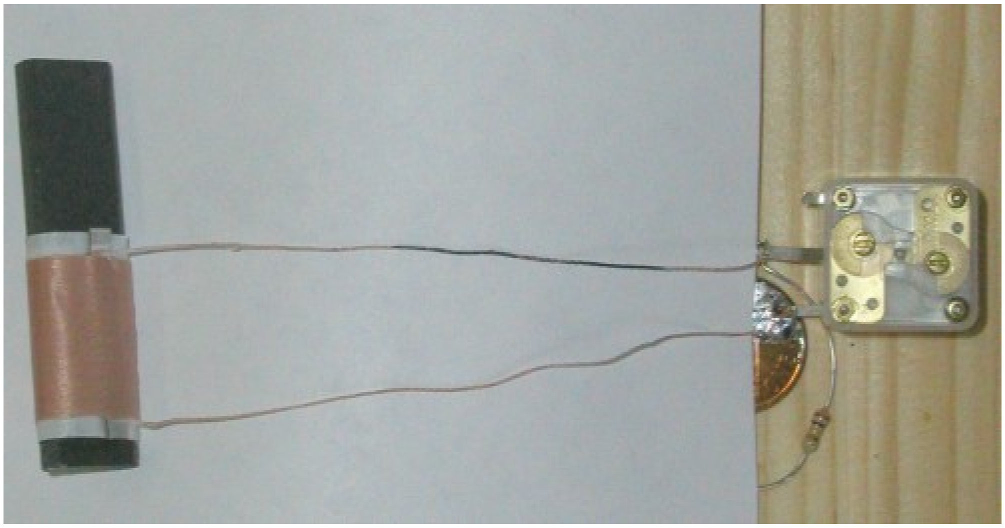


Click on photo for a larger picture

In the photo below, we have wrapped the red (positive) wire from the battery holder around the resistor wire. The black wire goes to the top right penny. Now we solder all of the connections.

Click on photo for a larger picture

If you are going to use lemonade for the battery, just solder a longish wire to each of these spots instead of the battery holder. I like to use red wire for the positive side, and black wire for the negative side, just like they do for the battery holder. This helps me remember which wire goes where later.

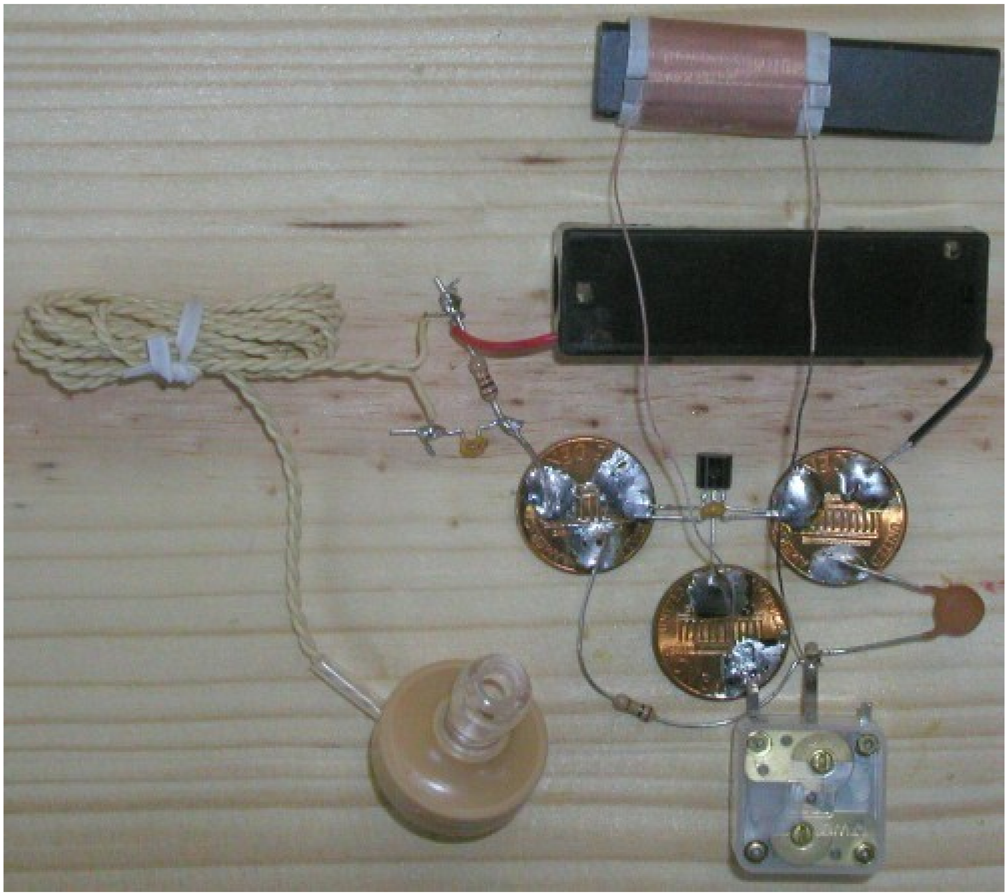


Click on photo for a larger picture

The next step is to solder the wires from the coil to the legs of the variable capacitor. In the photo above, I have placed a piece of white paper over the project, to make it easier to see the fine wires in the photo. You won't need the paper when you build the radio, it is just to make the parts in the photo easier to see.

If you are using the 4 wire coil from our catalog or the kit, connect the unpainted wire to the left terminal of the capacitor, and the black wire to the center terminal of the capacitor. The red wire is for an optional external antenna, and the green wire is for an optional ground connection. The radio works fin with these wires unconnected, but will pick up distant stations more easily if they are connected as we did in the 10 minute radio project.

The ferrite rod in the coil is not glued in place, and can slide easily into and out of the coil. This is important, because we will be sliding the ferrite rod in and out of the coil later, to adjust the tuning.



Click on photo for a larger picture

The photo above shows the project so far, without the paper in the way.

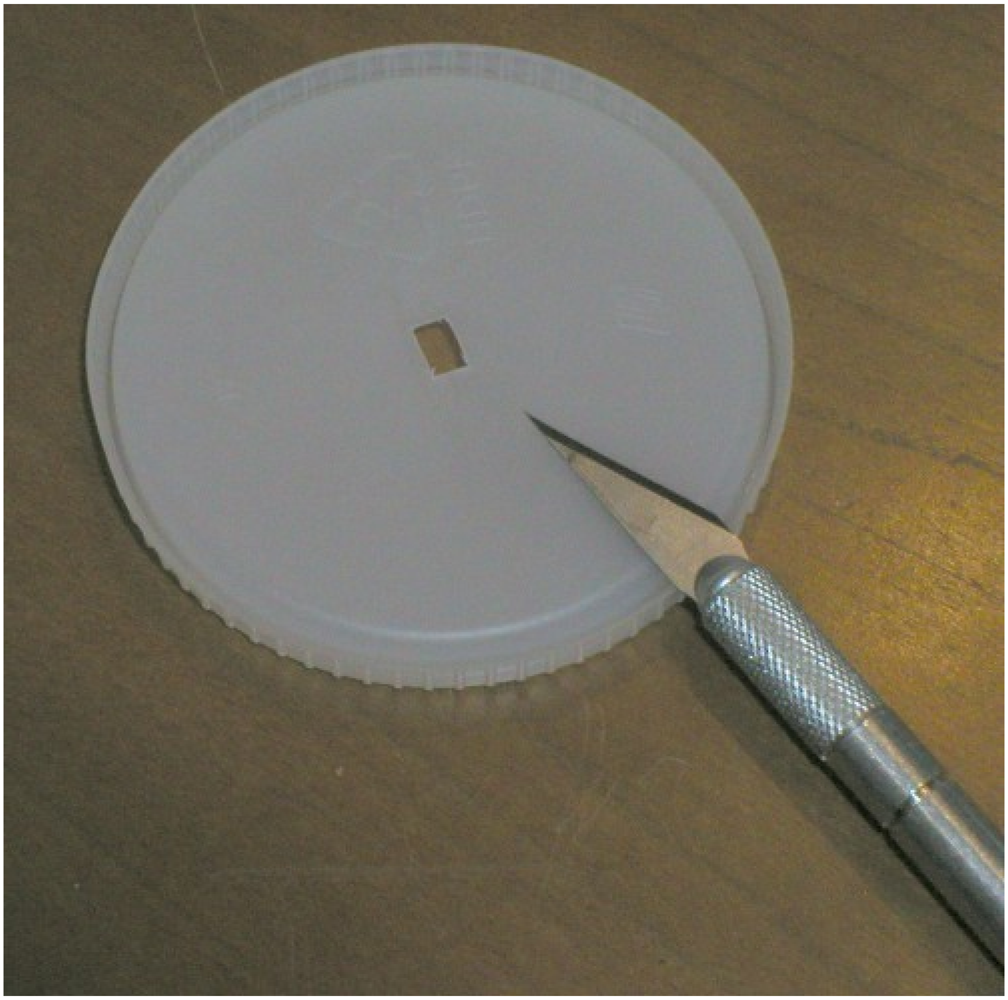
At this point the radio is actually complete. You can probably hear sounds from the earphone if you put the battery into the holder. We will discuss how to tune the radio in a moment.

Click on photo for a larger picture

Now we finally get to turn the radio over, so it is right-side-up. The photo shows three push-pins placed around the variable capacitor. We will discuss why in a little bit. The capacitor is now glued down to the board. You might notice that we are now using a nice clean board, since we are done soldering.

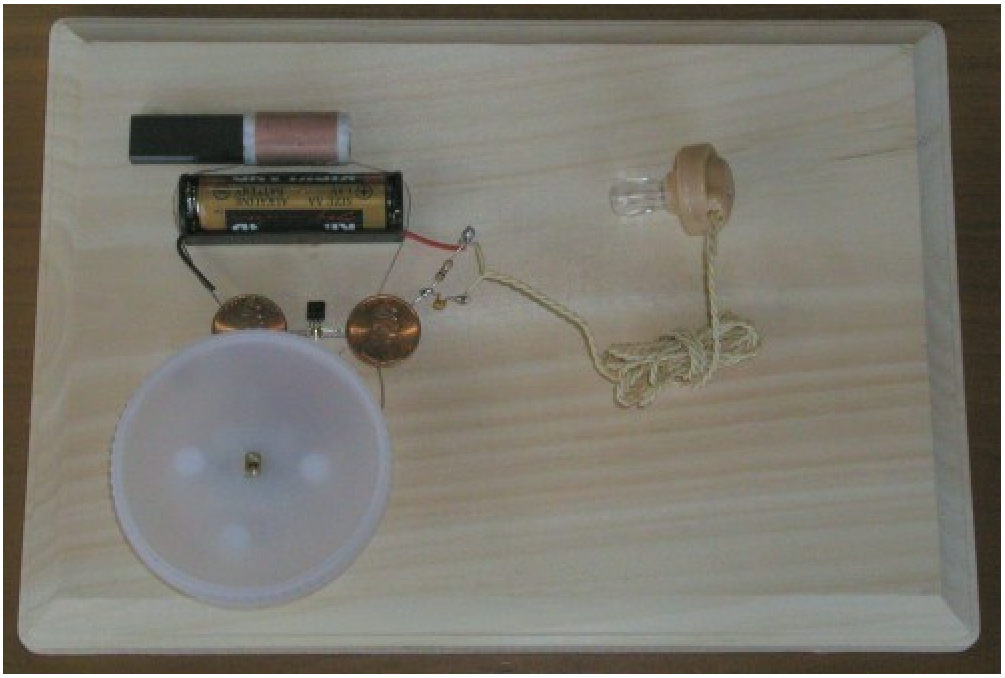
The radio can be used as it is (we will add a finishing touch in a moment). It is tuned in two ways. First, you can slide the ferrite rod very slowly into and out of the coil. This is a coarse adjustment, and getting exactly the station you want can be difficult this way, since a tiny movement of the rod can change the tuning to a different station.

Finer tuning is done by turning the brass rod in the variable capacitor. To make this easier to do, and to make it easier to make fine adjustments, we will make a large knob out of a plastic lid from a jar or can that we no longer need for anything else.



Click on photo for a larger picture

With a small, sharp knife, cut a small rectangle out of the center of the lid. The rectangle should be just a bit smaller than the brass rectangular top of the rod in the variable capacitor, so it will make a very tight fit when we press it onto the brass rod.



Click on photo for a larger picture

The photo above shows the tuning knob in place. The three push-pins hold up the knob so it doesn't wobble. With the large knob, it is easy to select just the station you want to hear.

Since the ferrite rod is still loose in the coil, the radio is not yet very portable. At this point you need to find out where to place the rod so that all of the stations in the AM band can be tuned using just the variable capacitor. This is done by turning the capacitor all the way to the left, and then sliding the ferrite rod into the coil until you hear the first station. Now you can tape the rod onto the board, or glue it there with some silicone rubber glue. You can also glue down the battery holder if you like.

Your Three-Penny Radio is now complete!

How does it do that?

At this point in the book, if you have been reading from the beginning of the chapter, you probably already know most of the science behind how this radio receiver works, since it is very similar to a crystal radio.

Like a crystal radio, this is a "Tuned Radio Frequency" receiver. That means it listens to the radio signal directly. It does not contain an oscillator like some other radio circuit designs (such as *superheterodyne* and *regenerative* radios).

The coil and variable capacitor join together to form a "tank circuit" that selects which radio station you want to listen to. Tank circuits, and capacitors are covered in considerable detail and length in the page called Adding a capacitor (or three) in the section titled "Building a crystal radio out of household items".

The main difference between this radio and a crystal radio is that the integrated circuit in this radio not only has the crystal inside it, but it has amplifiers and an Automatic Gain Control.

The antenna coil (the little coil with the ferrite rod inside) generates tiny amounts of electricity as the radio waves wash over it. An amplifier is a circuit that uses that tiny amount of electricity to control a much larger flow of electricity from the battery. It is like using the water from a garden hose to move the nozzle of a firehose, putting a huge amount of water anywhere you wanted it, using only a little water from the garden hose.

The Automatic Gain Control circuit controls how much amplification is used. It turns up the volume on weak stations, so they sound as loud as strong stations do. This is why we don't need a volume control on our radio -- all the stations are close to the same loudness (no AGC circuit is perfect -- you can still tell which stations are powerful nearby stations and which ones are far away or weak).

The piezoelectric earphone is also covered in the first page of the section "Building a crystal radio out of household items".

In the radio shown in the photos, we use a 1.5 volt battery (in this case a small "N" cell, but you could use a "D", "C", "AA", or "AAA" cell just as easily).

The radio will work with battery voltages as low as 1.1 volts, or as high as 1.8 volts. The current needed is very small -- only 3 milliamps. This tiny amount of electricity is easily obtained from homemade batteries, or small commercial solar cells.

Click on photo for a larger picture

One simple homemade battery is just a piece of crumpled aluminum foil in a stainless steel bowl of vinegar and salt. The foil is kept from touching the bowl by a piece of paper tower or newspaper.

Click on photo for a larger picture

The stainless steel bowl and aluminum foil must not touch one another. You can get higher voltage by connecting the bowl of one battery to the aluminum foil of the other battery (this is a *series* connection).

The radio needs between 1.1 volts and 1.8 volts to operate. But it also needs at least 0.1 mulliamps of current. The specifications say it needs 3 milliamps, but as you can see in the photo, we are using only 0.15 milliamps, and the radio has very nice volume.

The voltage is determined by how many bowls you have. The current is determined by how much surface area the bowls and aluminum foil have. Using bigger bowls and more foil will produce more current.

Click on photo for a larger picture

The bowl is the positive wire, and connects to the radio where the red wire from the battery holder went. The aluminum foil is the negative side of the battery, and connects where the black wire from the battery holder connected.

You can see the alligator clips attached to the battery holder if you look at the larger photo (click on the small photo).

You can try soft drinks, or lemonade instead of the vinegar. The salt usually helps a lot though. Some people power their radios with beer. Depending on the beer, you may need more than three bowls. Adding salt to the beer will keep it from disappearing into curious bystanders.

Some fun packaging

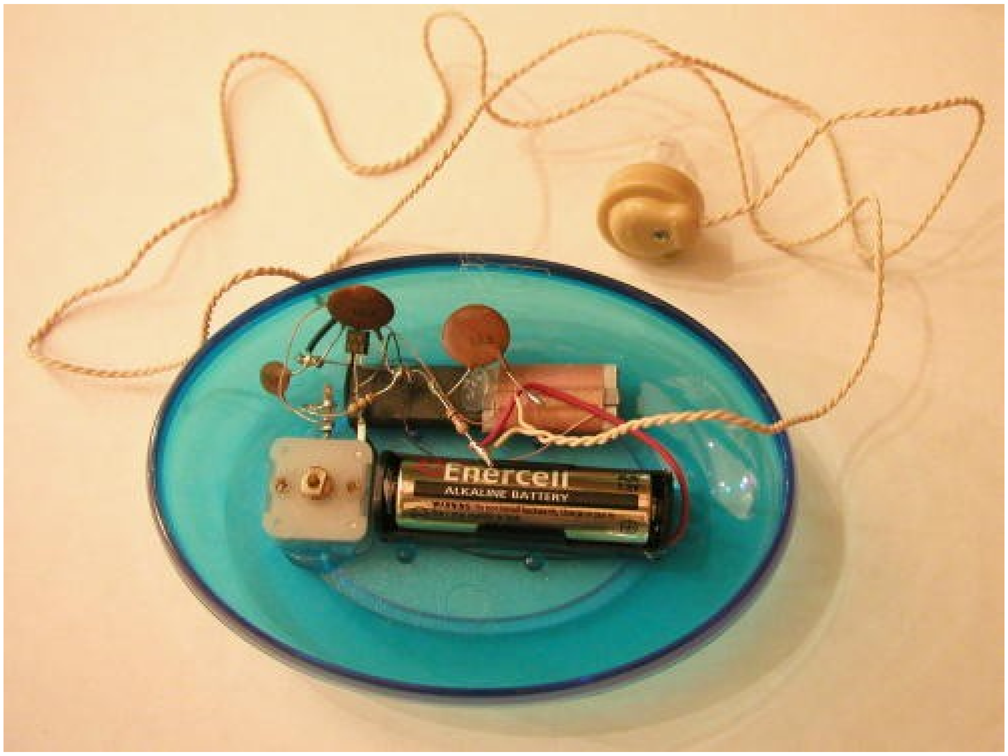
The Three Penny Radio is small enough to be fit into some fun and interesting containers. We found a nice wooden box at a local store, and built a radio to fit inside it.

Click on photo for a larger picture

Instead of pennies, we used upholtery tacks, stuck into a bit of cork for a base. The cork was cut to fit the box.

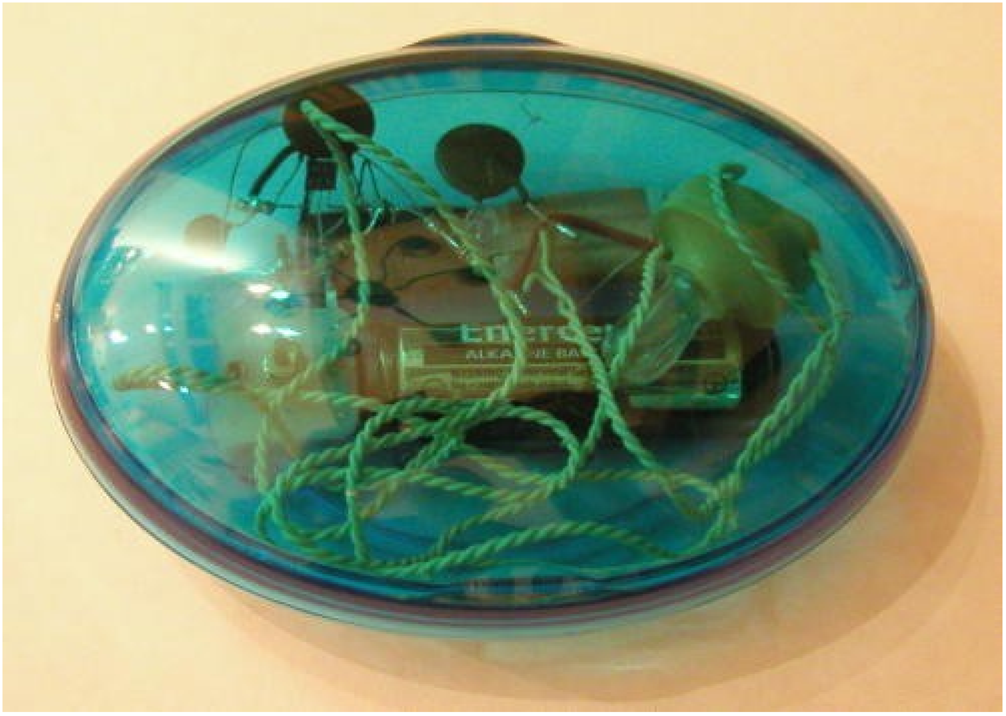
Click on photo for a larger picture

The tuning knob is a plastic soda straw glued to the brass shaft of the variable capacitor, and exitting out of a hole drilled in the back of the box. We used a small "N" cell battery which fits nicely in the box, and powers the radio for weeks (there is no off switch). You can remove the battery when not using the radio to make it last longer. The earphone coils up inside the box for storage.



Click on photo for a larger picture

At another local store we found a little soap dish that was just begging to be turned into a radio.

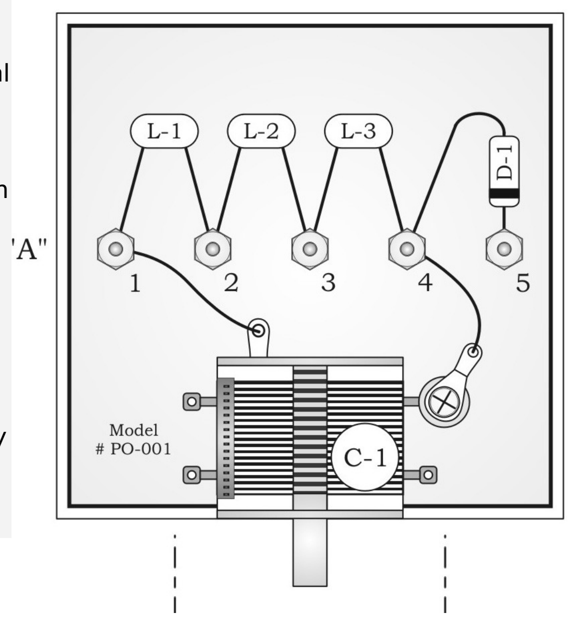


Click on photo for a larger picture

We cut s slot in the lid to let the earphone wire come out while the lid was on, so the radio fits in a shirt pocket nicely with the lid on. Like before, the earphone coils up inside the box for storage.

Article B1: How To Read Schematics

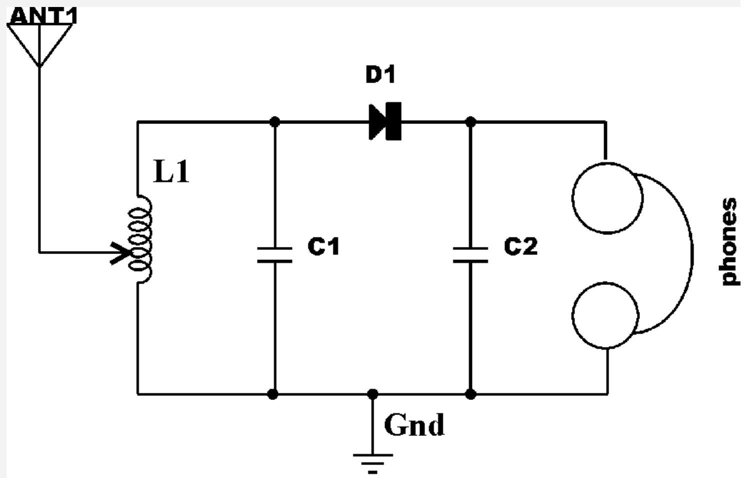
In the first half of the twentieth century, one could pick any number of magazines, like Mechanics Illustrated, describing crystal sets and other electrical devices. It was popular and practical to present a crystal set using a line drawing, such at that shown to the right, which is a portion of a crystal set designed by Mike Peebles and presented in the March 2005 issue of the Society Newsletter. These wonderful drawings not only presented an overall picture of the set but clearly displayed wire routing and other physical features.



As time marched on, designers found it quicker and easier to document the electrical aspects of sets using what we call today a schematic presentation. Schematics are two-dimensional, not pictorial. Nearly all articles or documents of electronics found today use this format. Pictures are not included generally, leaving wire routing and mechanic layout a potential

mystery. Too bad! Quality manuals and kits should include enough pictures to tell the story left untold without the old-time illustrated drawings.

Since schematics dominate now, let's see how to read them. We'll use the schematic of a basic crystal set, shown at right, as our example.



In order to represent a circuit on paper (in two-dimensions), symbols were developed for each type of component used.

- An antenna is often shown as an inverted triangle, as shown at upper-left.
- A section of hookup wire is drawn as a dark line, and an alligator or other clip at the end of the wire is drawn as an arrow.
- A coil, see L1 in the figure, is drawn somewhat like a mechanical spring, with a series of looping wires.
- A capacitor, which is generally constructed by arranging two metal plates one atop another with insulation in between, is drawn as two dark lines parallel to each other. C1 is a capacitor.
- The symbol for a detector diode is a bit more complicated and is shown in the figure as D1. Early diodes were constructed using a small wire – called a cat whisker – and a hunk of galena rock. The arrow on the symbol represents the wire pressed against the rock and the black rectangle denotes the body of the rock. Old style drawing would actually sketch out the rock. Today we're modern and have reduced that ragged rock to a rectangle.
- Headphones or earplugs are used to listen to the audio signal produced by a crystal set. The two circles and a strap connecting them make this symbol pretty obvious.
- For some time now, most schematics place a dark dot on lines that cross each other, if and only if those lines are connected physically. Note in the figure that a dot after the diode, D1, denotes that D1 is wired to one lead on the phones and to the top lead of capacitor C2. Saying it another way, the output lead of the diode is connected to the phones, and the output of the diode is also connected to one of the leads of the capacitor.
- Finally, the symbol at the bottom of the schematic, the arrow that is made up of a number of tapered horizontal lines (and labeled as GND) represents the electrical ground connection of the set. That means that the bottom of coil L1, the bottom of C1, the bottom of C2 and the second lead of the phones are all connected to the ground of the circuit.
- Extra hookup wire is generally required to interconnect the component leads, since these leads on each component are short. Hence, the line representing the lead from the bottom of coil L1 includes the coil lead and some hookup wire soldered together. The end of the wire then attaches to the ground or to one of the other components in the ground circuit.

Congratulations! You've just read your first schematic.

THE AM BROADCAST BAND

While crystal sets are designed, built, and used for the AM broadcast band and shortwave bands, the vast majority of hobbyists in the US focus their activities on the AM band, defined by the FCC to span from 530 through 1,700 kHz. As of January 1, 2008, there were roughly 4,793 AM stations active on the band, and this number of stations hasn't changed much over the last ten years. Power output assigned by license to these stations varies, from as little as 250 watts to a maximum of 50,000 watts. Format, i.e. the content broadcast by each station, varies. As noted in Figure 1, the concentration of AM stations assigned at each increment of 10 kHz in frequency varies across the band, numbering 25 at 540 kHz, averaging about 30 from 550 through 1200 kHz and about 65 from 1210 through 1600 kHz. Just a smattering of stations occupy segments from 1600-1700 kHz.

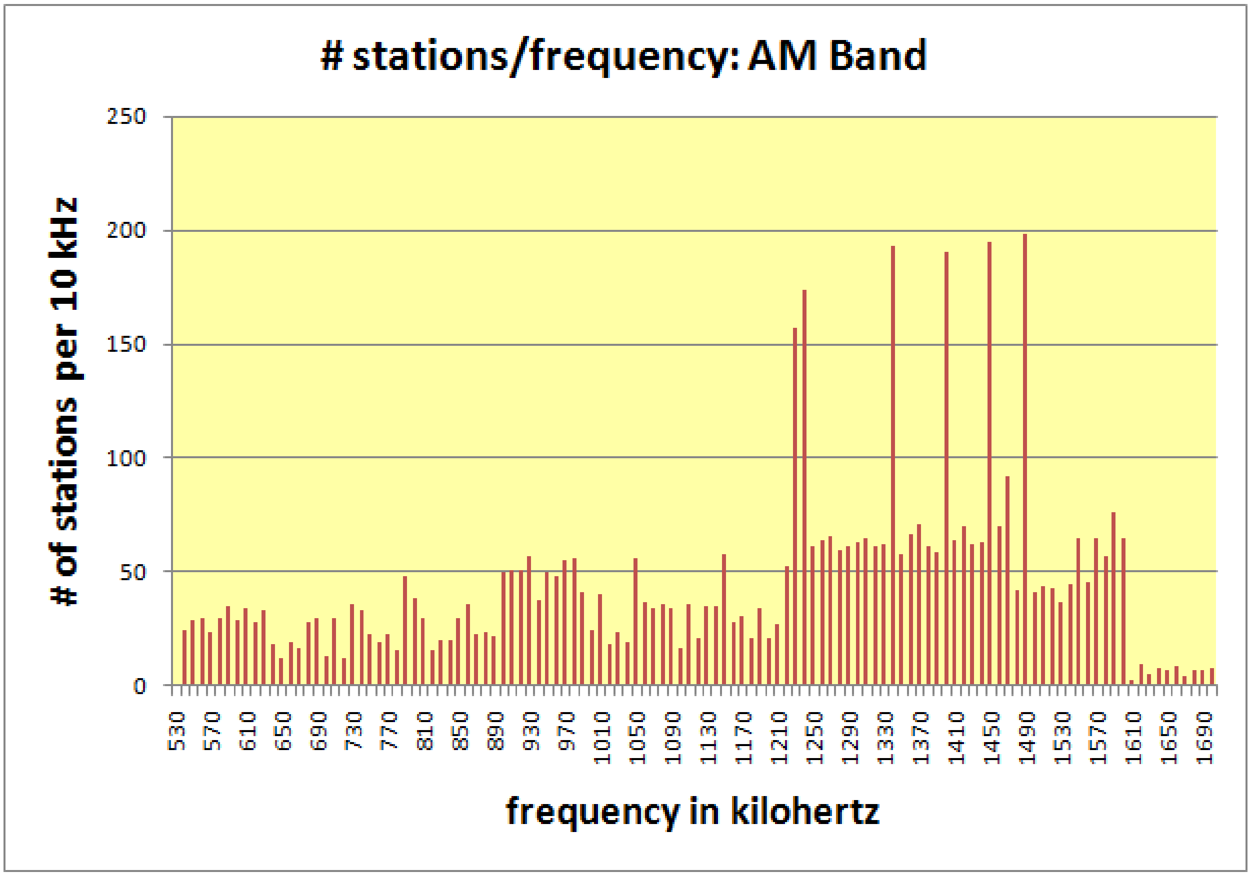
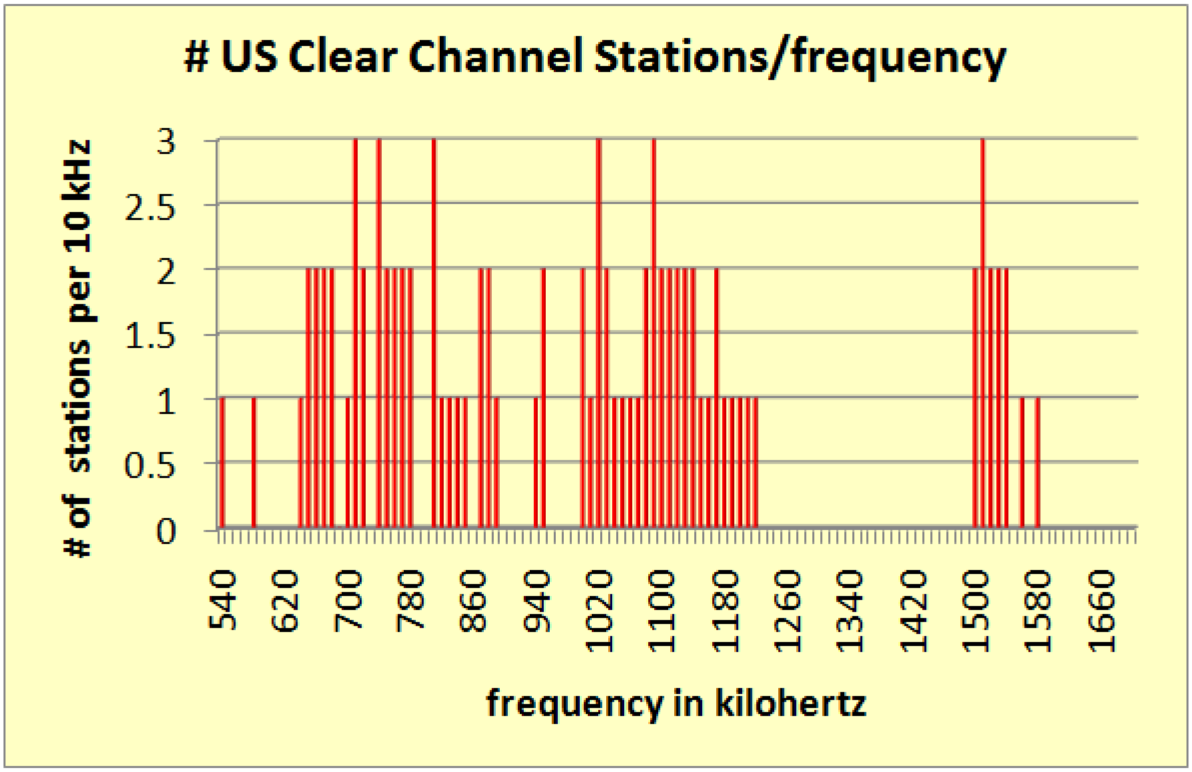


Figure 2 displays the concentration per frequency for the 50 Kilowatt stations that operate day and night. These stations - often called clear-channel stations – can cover a wide area at night as their radio signals reflect off the ionosphere. During the day, local stations are those most often heard, as long-distant reflections off the ionosphere are reduced. Clearly, we can use these facts to improve our listening and logging activities. During the day is the best time to receive or log those stations that are within a given radius of our location. At night the clear-channel stations will dominate and we'll tend to hear those whose antenna pattern (direction of transmission) and reflection pattern (for that day) off the ionosphere is aimed at our location. These patterns vary which is part of the fun of chasing stations, called DXing.



You can do a bit of research before listening to improve your chances. Compile a list of the stations near you and a second list of stations within a thousand miles of you. These data can be found at a number of websites that specialize in radio station data. Here are a few:

- List of stations by city; via amlog book, click on cities.
- List of 50 KW Stations; via AC6V
- www.radio-locator.com.
- www.fcc.gov/mb/audio/amq

For beginners, you'll want to look up the stations in your town or nearest city. Note these and adjust your crystal set to make sure that it is tuning these frequencies. You might check out the list of 50 Kilowatt nighttime powerhouses too and give them a try before bedtime! For you crystal set regulars, you likely know the drill already. You'll want to dig into the FCC data to determine which stations have an antenna pattern that will reach your location. You'll then be armed for listening. You have also or will likely study propagation phenomena to determine best time to listen. Happy DXing!

A BIG HUNK OF GALENA CRYSTALS

We recently sent Bill Simes, Overland Park, KS, a big hunk of galena rock. He responded on the phone with, "I can't break this up for mounted galena pieces; it's too nice. It's a museum piece. Why don't I mount it on a slab of walnut?" We agreed.

Today, 6-14-08, a Priority Mail Package arrived. You guessed it; Bill had mounted the Big Galena on a nice and shinny Walnut base. Ain't it pretty!

TheCrystal Radio FAQ

started by Steve Coles

I) Why bother?
II) Definitions
III) Simplifications & Lies
IV) Troubleshooting
V) How does a Crystal Radio Work? A lesson for beginners...

I) Why bother?

A) Crystal sets help us to understand the technical history of the 20th century.   Three, of many, examples: In very early commercial radio, crystal sets provided inexpensive receivers that allowed a large listening market to develop. During World War II, improved crystal diodes made British and American radar receivers more sensitive than German models. Crystal diode research provided materials and techniques used in the invention of the transistor.

B) Crystal sets provide a step-wise introduction to electronics. Most beginner crystal sets need only an antenna, ground, coil, capacitor, diode or crystal and headphones. Once these few components have been mastered, the student can advance step-by-step by adding a

radio-frequency transformer, a one-transistor amplifier and so on until an understanding of most common electronic components is gained.

C) Many modern electronic systems still contain crystal set-like circuits. A few examples: The detector section of AM radios, field strength meters (for measuring antenna performance), broadcast station air diodes (allowing a broadcaster to monitor a small sample of the transmitted signal), radar receiver mixers and instrument devices transferring signals generated at one ground reference voltage to processing circuits having a different ground reference.

D) Challenge and reward: A fourth grader can find satisfaction in successfully completing a simple kit while a subtle semiconductor problem can challenge a senior engineer or physicist.

II) Definitions

Each of these definitions will bring up new questions and, as Lawrence says, more interesting questions. For instance, understanding a capacitor requires understanding conductors, insulators, electric charge, electric fields and how energy is stored in an electric field. You might need 5 new definitions. You'll need an electronics dictionary and a general introduction to radio. Make sure you can understand what you're buying. I've seen technical dictionaries at level's from fourth grade to postdoctoral. [Any recommendations here?] The following provide a minimum starting point for terminology:

AM (amplitude modulation). In AM radio, music, voice or television signals are impressed on a radio carrier wave by varying the wave's amplitude. In contrast, FM impresses music, voice or other signals on a radio wave by varying the wave's frequency.

Antenna. For crystal radios an antenna is an electrical conductor in which a radio wave induces small currents and voltages. A 15 meter wire suspended 3 to 5 meters above the ground and insulated from other objects usually serves well as a crystal set antenna. You may know that a magnet moved near a coil induces a current in the coil. You may also know that a charged rod held near an uncharged rod causes charge to separate in the uncharged rod. The electromagnetic wave we call a radio wave induces voltages and currents in an antenna in much the same way.

Capacitor. Two sheets of conductive material separated by an insulator form a capacitor. Crystal-set builders sometimes make a capacitor by sandwiching a sheet of picture glass between two sheets of craft copper foil. Commercial capacitors are often named for their insulating material, such as ceramic of mylar. A capacitor stores energy in its electric field. A capacitor supplies energy to the headphones during the part of the cycle that the detector diode is switched off. Resonant circuits also use capacitors.

Cat whisker (AKA, "cat's whisker"). A cat whisker is an (often springy) piece of pointed wire. It presses against a piece of semiconductor such as galena, iron pyrite, germanium or silicon. Usually, it provides the anode end of a diode detector. A variety of conductors have been employed as cat whiskers. I've used safety pins and partially straightened phosphor-bronze ball-point pen springs. If you have a glass enclosed germanium diode (available from Radio Shack), you can use a hand lens to see the cat whisker inside. You may have to scrape some paint off. You can even smash the glass and experiment directly with the cat whisker and germanium crystal individually. I've used the crystal from the diode with other pointed wires as cat whiskers. In principle you could use the cat whisker from the diode with some other semiconductor such as natural galena or fool's gold from a rock-hound shop. In junction diodes the connecting wires play no role in diode action. Therefore, junction diodes don't have cat whiskers in the same sense point-contact diodes do.

Coil. Simply a coil of insulated wire wound around an insulating support (often a mailing tube in crystal sets). A coil stores energy in its magnetic field. Combined with capacitors, coils form resonant circuits. Taps on coils assist in impedance matching.

Condenser. Condenser is an older word for capacitor.

Conductor. Anything that electricity easily flows through. Conductors include wire, capacitor plates, bolts, screws, iron pipes and damp salty ground. When a conductor fails (perhaps by breaking mechanically or oxidizing), the barrier to electricity is called an open circuit.

Crystal. A piece of semiconductor material. Some crystals, such as galena and iron pyrite (fool's gold) occur geologically. Modern crystals, such germanium, silicon, gallium arsinide and even diamond and some plastics are produced by carefully-controlled laboratory or industrial processes. For a natural crystal to show diode action, it must be mechanically clamped or set in a small cup of solder. A wire attaches to the clamp or solder cup. Then a cat whisker point is moved into contact with a sensitive spot on the crystal.

Detector. As an AM radio wave is received, the negative-going half cycles cancel the positive-going half cycles. In AM the detector is a crystal or diode that removes the negative-going (or positive-going) half cycles.

Ground. 1) In crystal set usage an electrical connection to a conductor buried in the ground. Often a ground is achieved by a copper clamp to an iron cold water pipe where it enters a building from underground. 2) In much of the remainder of electronics, ground means a common conductor to which most voltage measurements are referenced.

Headphones. The same idea as portable radio headphones with one important difference. Portable radio headphones are designed to work with the ~16 ohm output impedance of the radio's integrated circuit amplifier. Crystal set phones must have a characteristic impedance of 600 ohms or more depending on the crystal set.

Inductor. Inductor is another word for coil.

Insulator. 1) Any material that does not conduct electricity or that conducts electricity very poorly. 2) An object made to prevent electricity from flowing through an unwanted path. When an insulator fails, the path followed by the electricity is called a short circuit.

Leyden jar. Early electrophysicists performed capacitor experiments using a type of capacitor called a Leyden jar. Some general science and physics books discuss the properties of capacitors under the heading of Leyden jar. A Leyden jar can be assembled from a fruit canning jar and two pieces of aluminum foil.

Resonant circuit. When a coil and capacitor are electrically connected they can trade energy back and forth between the magnetic field of the coil and the electric field of the capacitor. The trade takes place via the current flowing between the coil and capacitor. Physics dictates that for any particular coil and capacitor, there will be a finite time for the energy to transfer from coil to capacitor, back to the coil (with reversed voltage polarity), and finally back to the capacitor with the original polarity. The number of such cycles in a second is the resonant frequency of the circuit [in units of cycles per second or Hertz (Hz)]. Crystal sets use resonant circuits to send a desired station to the detector while bypassing all other stations to ground.

Searching a crystal. When using a natural crystal, only small areas of the surface have the correct properties for diode action (rectification). The cat whisker must be moved around the crystal until a "sensitive" spot is found.

Solenoid. 1) In applied electricity a solenoid is a type of electromagnetically operated actuator and has almost nothing to do with crystal sets. 2) General science and physics

books often use "solenoid" to mean a single-layer coil such as we use in the resonant circuit of a crystal set.

Tap. A tap is an electrical connection made to some point on a coil other than an end. Taps are used for impedance matching and for changing tuning ranges.

Tuned circuit. Tuned circuit means the same as resonant circuit.

Variable. One of a resonant circuit parts of a crystal set--either the coil or capacitor--is made variable to allow different stations to be tuned in.

Wave. A radio wave consists of a magnetic vibration and an electrical vibration superimposed on each other. If we could watch an AM broadcast wave approach us, the magnetic part would look something like a rope being shaken left to right and the electric part like a rope shaking up and down.

III) Simplifications & Lies

To give a first cut at visualizing these things, I made a couple statements above that ain't quite so.

A) In reality, amplitude modulation consists not in varying the carrier amplitude, but in attaching sidebands (additional frequencies) to the carrier. Ditto FM.

B) It's often better to think of the field around a wire, rather than the current passing through it, carrying the energy. The energy is transferred at the rate the field travels, not the much slower electron speed.

IV) Troubleshooting

1. Make sure the enamel insulation on the coil wire is in good shape, except where it must be sand papered off for slider contact.

2. Make sure enough insulation has been removed from the wire ends where they need to make contact with wires from other components. Sand paper works OK for removing enamel insulation.

3. Make sure the headphones are crystal or high impedance (about 2000 to 4000-ohm) types. If you must use low-impedance phones (most sold with an 1/8 inch--about 3 mm--stereo phone plug are low impedance), then use a matching transformer. (Most Radio Shacks carry a transistor output transformer that works).

4. The antenna wire needs to be about 45 feet (15 meters) long if you're not within a few kilometers of strong stations. Be sure your antenna wire is well insulated from nearby metal objects. If your antenna passes into the house through anything metallic (aluminum siding, aluminum window frames, etc.), then make sure it's well insulated from the metal objects. You can pass the wire through small-gauge flexible plastic tubing from model airplane shops.

5. Be sure you have a good cold water pipe or 4-foot rod ground connection. Remove oxidation from the surface of the pipe or rod with sand paper before making the connection. Don't just tape the wire on and hope for a connection. Use a copper ground clamp from a hardware store. The ground is just as important as the antenna.

6. Be sure the slider wire (ball, strap) presses firmly on the part of the coil you've sanded the insulation off of.

Lots of crystal set configurations work. Try a variety.

How a Crystal Radio Works (for beginners) by John Davidson

Radio stations convert sounds into radio waves and send out the waves everywhere. Radio waves travel across the crystal radio antenna all the time. Radio waves make radio wave electricity flow between the antenna wire and the ground wire. This electricity is connected to the crystal radio. The crystal radio uses a tuner to tune the electricity to receive just one station. Then it uses a detector to convert this radio wave electricity back to sound electricity. It uses an earphone to convert the sound electricity to sound you can hear.

For more help check our FAQ.

Crystal Radio

A crystal radio is the simplest kind of radio. Most radios you buy use complicated electronics to make a strong copy of the sound. A crystal radio is a simple kind of radio that just picks up the wave and changes it straight into sound. It does not use separate power or batteries to make a stronger copy of the sound. It gets all of its power only from the radio wave.

Radio Waves

Radio waves are invisible waves of electricity and magnetism. Each radio station sends out radio waves. They travel out from the station something like water waves travel out from a splash in a pond. Water waves travel slow, about 10 miles each hour. Radio waves travel very fast, at 186,000 miles each second.

Tuner

The tuner separates one radio station from all the others. Different radio stations send out waves that have different space between them. A station at "600 kHz" on the tuning dial sends out radio waves with twice as much space between them as one at "1200 kHz". Also, a station at 1200 kHz sends out twice as many waves per second as one at "600 kHz. The number of waves per second is called frequency. The tuner uses the radio station frequency to separate stations and tune in only the station you want. The tuner uses resonance to make the radio sensitive to just one frequency at a time.

KHz

KHz is short for kilohertz. It is the numbers we see on the radio tuning dial. This is the way radio stations are separated. When radio first started, before 1920, tuning dial numbers gave the distance between waves. Engineers call this distance the wavelength. Today it is how many waves hit the antenna in a second. When the waves are closer together, like for a station at 1200 kHz (kiloHertz), there are more waves per second crossing the antenna. When the waves are far apart, there is a longer time between waves. Today the tuning dial numbers are waves per second. Engineers call this number the frequency. Today's AM broadcast band has the frequencies between 535 kHz and 1610 kHz.

Antenna Wire

The antenna wire picks up the radio wave electricity. A crystal radio needs a long antenna wire. Big antennas pick up more radio wave electricity. The antenna wire is just any electric wire that goes from the radio high up in the air. Longer than 80 feet is good. It works better outside and high up. Higher than 20 feet high is good. A good crystal radio antenna can be a small copper wire going out of a window and up high in a tree. Short antennas in the house work a little bit. Antennas near power lines are dangerous and do not work well.

Ground Wire

The ground wire connects the radio to the dirt. The dirt conducts electricity enough to give the antenna electricity some place to flow to. The ground wire helps the antenna get more power from the radio wave. A ground wire goes from the radio to something metal that goes into the dirt. The metal thing that touches dirt is called ground.

Ground

Ground is a metal thing that connects to something big, like the world. Dirt is a good ground. It gives the antenna electricity a place to flow into and out of. A good ground is a metal pipe several feet down in the dirt outside. Cold water pipes are good. They go in the ground on one end. Your body acts like a ground a little bit. Your body is too small and does not work well.

Radio Wave Electricity

Radio wave electricity is electricity that radio waves make in the antenna wire. Radio waves hit the antenna something like ocean waves hit the shore. Ocean waves make water rush up and back with each wave. Radio waves make electricity flow up and down in the antenna wire like that. Radio wave electricity flows back and forth about a million times each second. It changes back and forth faster for a shorter distance between the waves. Engineers call this Radio Frequency electricity, or RF.

Detector

The detector changes the radio wave electricity into sound electricity. Radio stations make the radio waves get stronger and weaker as the sound changes. The strength of the radio waves copy the sound vibrations. The detector changes the back and forth radio wave electricity into one way sound electricity. When the radio wave is strong, it makes strong sound electricity. When the radio wave is weak, it makes weak sound electricity. This makes sound electricity that copies the sound vibrations.

The detector works by letting electricity flow one way but not the other. Normal wires let electricity flow both ways.

When radio first started, inventors found rocks that work for detectors. They were crystal rocks, like galena, pyrite and lots of others. That is where the name Crystal Radio came from. Now detectors are made with wires on them. Engineers call them diodes.

Earphone

The earphone makes sound you can hear out of the sound electricity. The earphone connects the sound electricity to an electromagnet. The electromagnet pulls on a thin metal plate that can move. The electromagnet makes the plate vibrate and make sound. When we hold the earphone to our ear, we can hear the radio. The sound is not very loud. That is because the radio gets all its power from the radio wave. The wave does not have much power. You need to add more power from a battery or plug to make it louder. That takes complicated electronics.

Resonance and frequency

Resonance happens in electric circuits and in mechanical things. It is easier to understand in mechanical things first. If hang a small weight on a string one about 9 inches long (about 23 cm) it will swing back and forth one time each second. If you try to speed it up of slow it down, you can't. It swings at just one frequency, which is one cycle per second. That is resonance. The string and weight is resonant at one cycle per second. To make it slow down by half, make the string twice as long. The length of the string changes the resonant

frequency. You can say that the length of the string "tunes" the resonant frequency.

For electricity, a coil and capacitor make a resonant circuit. The capacitor plates get an electric charge from other parts in the radio. That charge flows through the coil. As it does, it builds up a magnetic field in the coil. When all the charge is gone from the capacitor, the magnetic field makes the electricity keep on flowing a little. This charges the capacitor plates the opposite way. As the opposite charge builds up on the capacitor plates, it finally stops the charge flow in the coil. Then the charge in the capacitor plates makes electricity flow the opposite way through the coil. That builds up a magnetic field in the opposite direction. The charge swings back and forth between the coil and capacitor at one certain frequency. That is the resonant frequency of the coil and capacitor.

Frequency is measured in cycles per second, and also in Hertz, abbreviated Hz. and in kHz. andMHz.

Coil

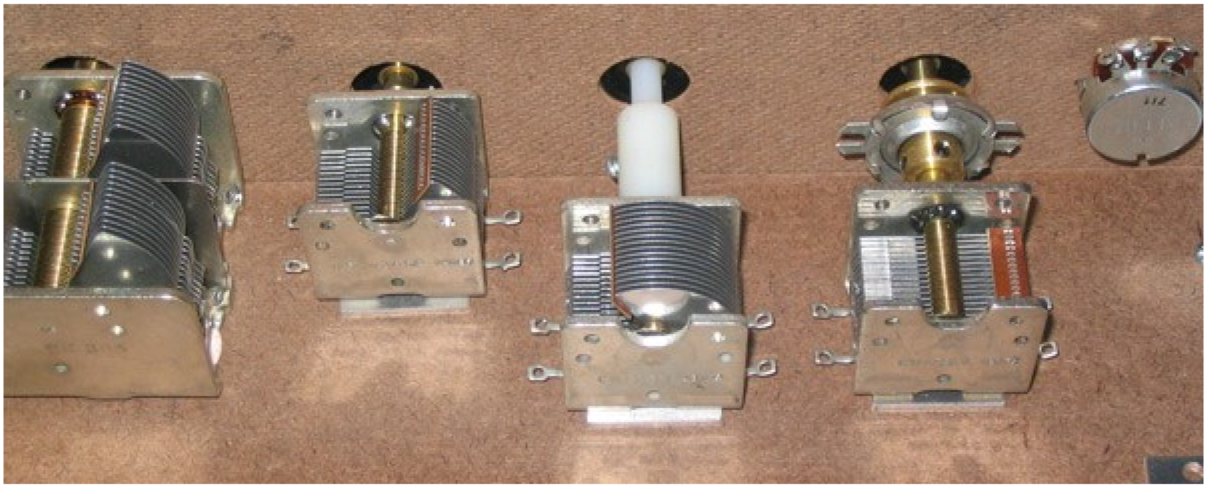
A coil is a length of electric wire wrapped around and around to help it make a strong magnetic field. There are many forms for a coil. When other parts in the radio make electricity flow through the wire, the coil builds up a magnetic field. This makes the electricity want to keep flowing even after the cause is taken away. The effect is measured in Henrys, or Micro Henries.

Capacitor

A capacitor is two metal plates separated by an insulator. A wire is connected to each plate. A capacitor will hold electric charge something like a rechargeable battery. When something puts positive electric charges on one plate and negative electric charges on the other plate, the capacitor holds that charge. It holds the charge because there is no electrical conductor path inside the capacitor. If there is an electrical conductor path outside the capacitor, the charges in the capacitor will flow around the path as electricity and the charge will be lost.

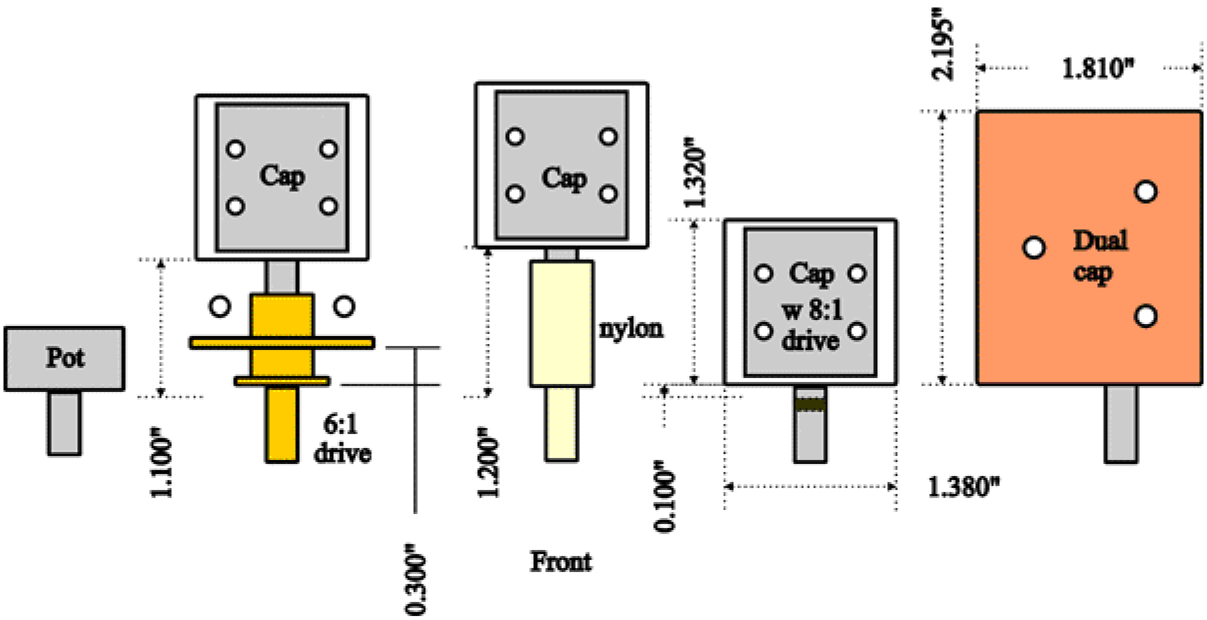
For crystal radios, most outside antennas act like capacitors. The antenna wire is one 'plate' and the ground beneath it acts like the other 'plate'. That is how a coil can resonate with an antenna to tune a crystal radio. This lets some crystal radio circuits tune with only a coil and no capacitor. The antenna acts as the capacitor while it also picks up the radio wave signal.

Variable Caps & Mounting



This article is made available to assist you in using/installing the air variable capacitors offered in our parts catalog. At this time, three caps are offered: a 365 pf dual-gang, a 365 pf single-gang with 8:1 reduction drive built in the shaft, and a 365 pf single-gang.

The 365 with 8:1 reduction drive is shown second from left. Physically is appears exactly the same as a 365 without the drive, except for a slight slot in the shaft (barely visible in picture). The reduction drive reduces the rate of rotation of the rotor plates to 1/8th that of the knob shaft, enablng finer

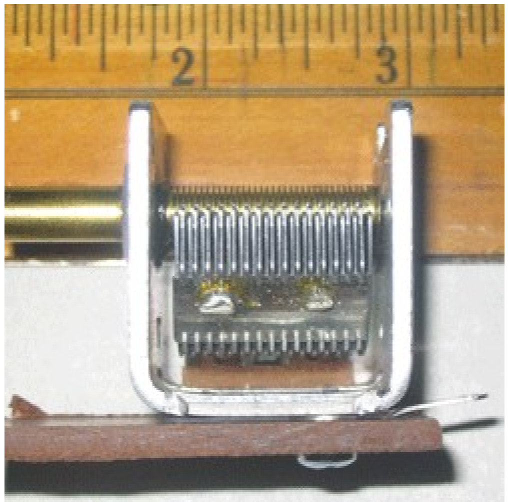


tuning.

The two caps to the right are 365s without shaft reduction. A half-rotation of the knob fully turns the capacitor plates. While often installed snug against a front panel - like the second cap - these two are set back 1-inch to accommodate shaft extensions. The white shaft is a combination of two nylon insulators, XS-NS1 & XS-NS2, used to reduce "hand capacitance" if desired. XS-NS-2 is 1 inch long with OD = 0.5 and ID = 0.257. XS-NS1 slips into XS-NS2 and is 1.5 inches long with OD = 0.25. To secure these together and on the shaft of the XS-365, you make two 4-40 tapped holes in the XS-NS2 and all is secured with 4-40 by 1/4 inch screws. The second 365 cap is shown with a 6:1 planetary reduction drive attached. While not shown, it is possible to build an assembly with the 365-8-1 and 6:1 drive combined, creating a whopping 48:1 reduction in cap plate to knob rotation.

The graphic at right denotes various dimensions of the items in the picture. The graphic is flipped upside down. A full scale 1-1 graphic pdf file can be downloaded from the articles-index page. The dual-gang, at far right, accommodates (3) 6-32 screws for mounting, and the front is shown to be 0.1 inches back from the front panel. The panel opening for the shaft is 1.250 inches above its bottom.

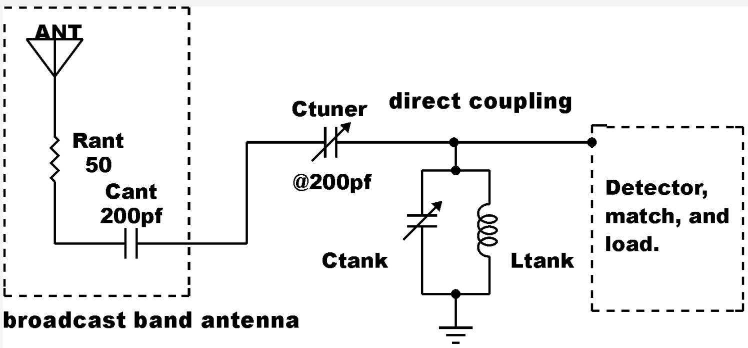
The 365s are shown mounted on a gray 060 aluminum shim, listed with the cap in the catalog. The shim holes align with the (4) 6-32 tapped holes in the bottom of the caps. The shaft is 1.020 inches above the cap bottom, including the 060 shim. One can mount the caps on #6 solder lugs instead; these are generally 040 in thickness after tightened down.



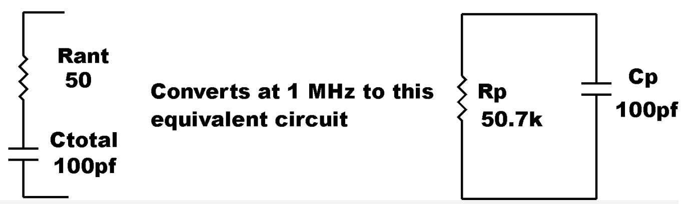
Care must be taken in mounting any of these caps to a chassis, in order to not short out or bend the stator plates with the mounting screws. In addition a shim or solder lugs are necessary to protect the small phenolic board that extends down on each side. Without the shim or lugs, tightening the cap to a chassis with screws can crack the boards. The picture of right displays the clearance necessary. The facing phenolic board used to mount the stator has been removed. Note that a 6-32 by 1/4 screw just fits through the 1/8th inch brown hardboard, through the solder lug and the base of the cap. Pick the screw that matches with your board or chassis thickness.

Electrical connections to the stator of all of these capacitors must be via the frame, as noted in the picture at right. One can attach a solder lug as shown or attach it to the bottom side of the board. The rotor connections are always on the sides of the capacitor and are common to both sides. As such the 365s have 4 common (conductive) solder lugs, two on each side. *The two capacitors in the dual-gang have a common rotor* and are in common with the frame. Each cap has separate stator solder lugs, one on each side.

Article 1: Equivalent Series and Parallel Circuits



A series circuit consisting of a resistor, capacitor, and inductor always has an equivalent parallel connection, and vice versa, at one frequency. A proof of this concept and the formulas listed below can be found in most introductory textbooks on electronics. The concept is useful for crystal sets in determining the load an antenna places on the tank circuit (LC) when capacitive-coupled, among other things.



As shown in the Figure, a short end-feed broadcast band antenna is connected in series with a tuning capacitor attached to the top of an LC tank. This arrangement can be tuned to match the antenna to the set *at a specific frequency*. The following formulas determine the effective resistance and capacitance presented in parallel to the set (tank circuit):

$$X_p = \frac{R^2 + X^2}{X} \frac{{}^2 + X^2}{R}$$

where R is the series resistance (of the antenna) in ohms, X is the series capacitive reactance (of the antenna capacitance in series with the tuner cap) in ohms, Rp is the effective parallel resistance and Xp is the resulting capacitive reactance.

Capacitive reactance – the AC resistance of a capacitor – at a given frequency is, of course,

$$X_C = \frac{1}{2\pi f C},$$

where C is capacitance in farads, f is frequency in hertz, and XC is the capacitive reactance in ohms.

For the specific application of matching an end-fed broadcast band antenna to a crystal set, the formulas can be simplified without losing much accuracy. The series resistance of a short end-fed vertical ranges typically from 25 to 100 ohms. The antenna capacitance ranges from about 100 to 600 pf; so, the reactance is large compared to the resistance. Given this, the R2 factor in the equations can be left off, resulting in these simplified formulas:

$$X_p = \frac{X}{R}, \text{ and}$$

Thus simplified, one can see quickly the values of the parallel components – *at one frequency* – given the serial components. The parallel resistance, RP, dramatically increases compared to the series resistance and is proportional to the square of the frequency. The capacitive reactance – and thus the capacitance – remains about the same.

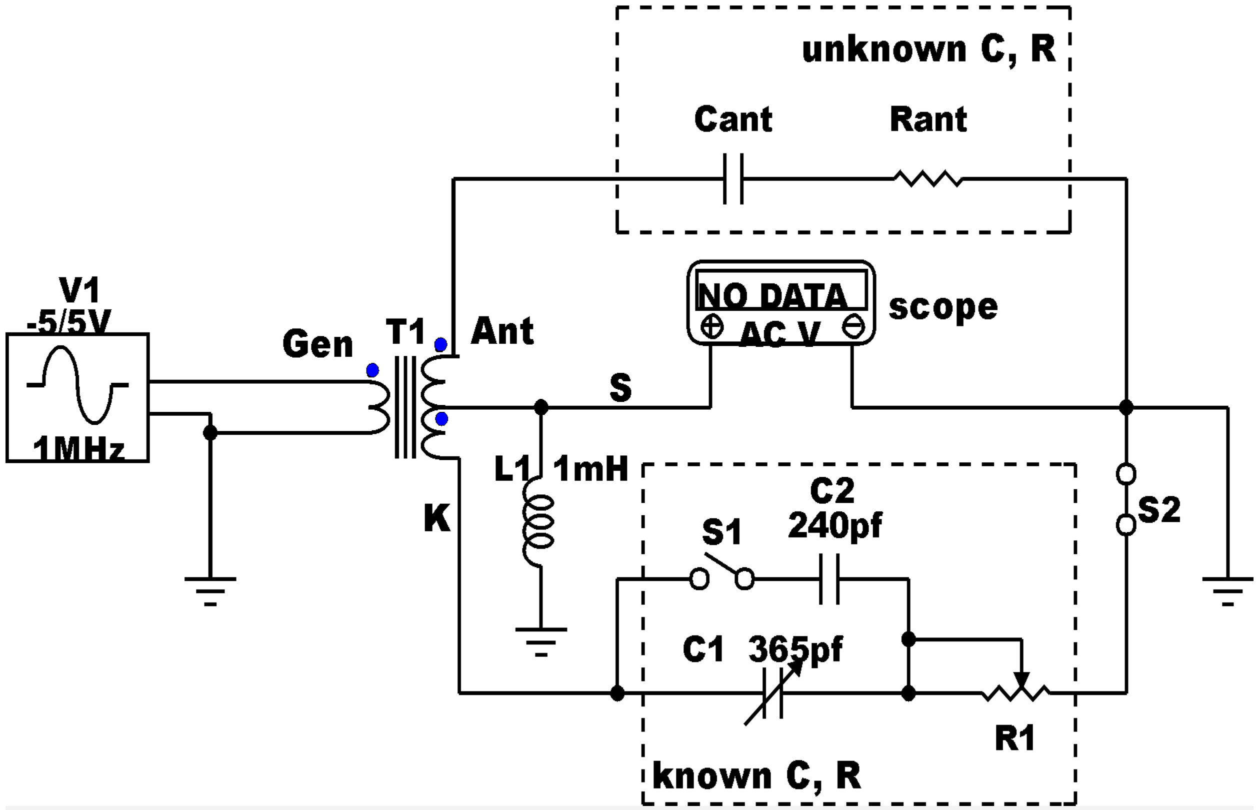
As shown in the bottom of the Figure, the 50 ohms and 100 pf of an antenna and tuner are shown to be equal to a parallel circuit of about 100 pf and 50.7K, at 1 MHz. Use the formulas to compute what the parallel values will be at 500 and 1,500 kHz.

Article 2: XS-800 Antenna Measurement Bridge

By Phil Anderson, WØXI

If an RF generator and scope are part on your bench, then the Hybrid-Coil RF Bridge shown in Figure 1 can be used to measure the capacitance and resistance of your end-feed broadcast band (BCB) antenna. With known antenna impedance, your crystal set can be optimized. While a Wheatstone bridge is often suggested, the configuration usually mentioned requires that headphones or meter with diode be used and that either must be floated (not connected to ground), given that the generator is referenced to ground. Our bridge utilizes a trifilar-wound broadband transformer feed, enabling an oscilloscope to be used as the meter and referenced to ground.

Figure 1: Antenna Measurement Bridge.



The bridge consists of three sections: the transformer, T1, your antenna to be measured, and an RC series circuit with known values. T1 consists of twenty trifilar-wound turns on an FT-140-61 ferrite core. Black, yellow, and red #26 hookup wire were used. One end of the black lead was grounded, leaving the other for generator attachment. Since the bridge requires a center-tap, the red lead on one end of the core was connected to the yellow lead on the other end of the core, as noted by the "dots" on the transformer in the schematic. A 1 mH choke was added at the tap, connection "S," to eliminate any 60-cycle buildup. The antenna connects to one end of the transformer, position "ANT." The known components make up the other branch of the bridge. C1 is a calibrated 365 pf air variable capacitor, and C2 is a 240 pf mica capacitor. Switch S1 is closed to add additional capacitance. R1 is a 100 ohm ceramic potentiometer. S2 is opened (after antenna measurement) to measure R1 with a VOM. The bridge, of course, must be attached to antenna ground, shown at right.

My bench, for this application, consists of the following: a B&K Precision 4017B 10 MHz signal generator, a Tektronix 2445 150 MHz scope, the bridge, and a TES 2360 LCR Multi-meter. My antenna is 100 feet in length: 30 feet up to the eve of the house, 50 feet horizontal to the other end of the house, and a horizontal ninety-degree dog-leg of another 20 feet above the garage. A 500-watt AM station at 1320 kHz is five miles off.

Measurements are taken as follows:

- Set the generator frequency, e.g. 500 kHz, and voltage output. I usually use 10vpp. Generally, be quick and use the minimum voltage necessary to take the measurement, so as not to interfere with other listeners.
- Attach one channel of the scope to the transformer tap, point S. Set the scope timing such that a couple of RF cycles at the frequency of interest can be displayed.
- Close both S1 and S2.
- Attach the antenna.
- Adjust C1 and R1 for a minimum reading on the scope.

- Log the capacitance of C1 and C2, and open S2 to measure R1. C1 & C2 represent the effective capacitance of your antenna. R1 denotes the resistance and ground-return of your antenna system.
- If the variable capacitor has not been calibrated, open S1 and S2 and measure the capacitance with a meter, such as the B&K-810C.

Figures 2 and 3 display the results obtained at 1 MHz. Figure 2 shows the voltage obtained with C1 fully meshed. Figure 3 denotes the minimum voltage with C1 & C2 and R1 adjusted to match the antenna. Note at the minimum that my local station signal, 1320 kHz, is all that is left; and, it's value is less than 100 mvpp. No 60 cycle energy appears in either case, as L1 was added to the bridge.

Figure 2: Scope Picture of C1 Fully Meshed.

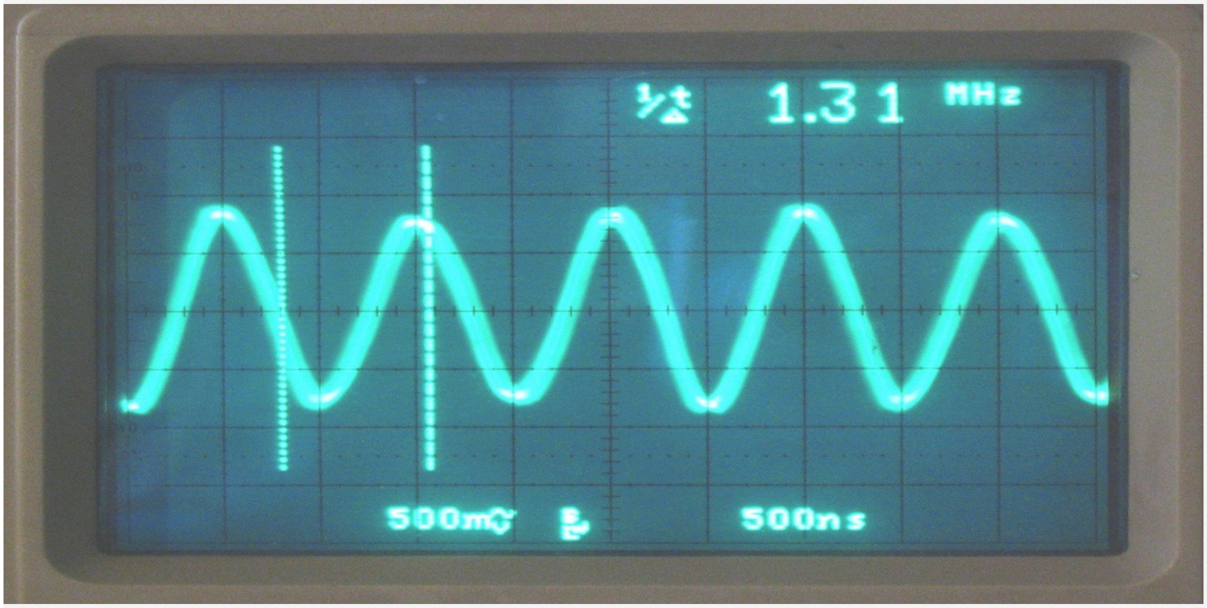
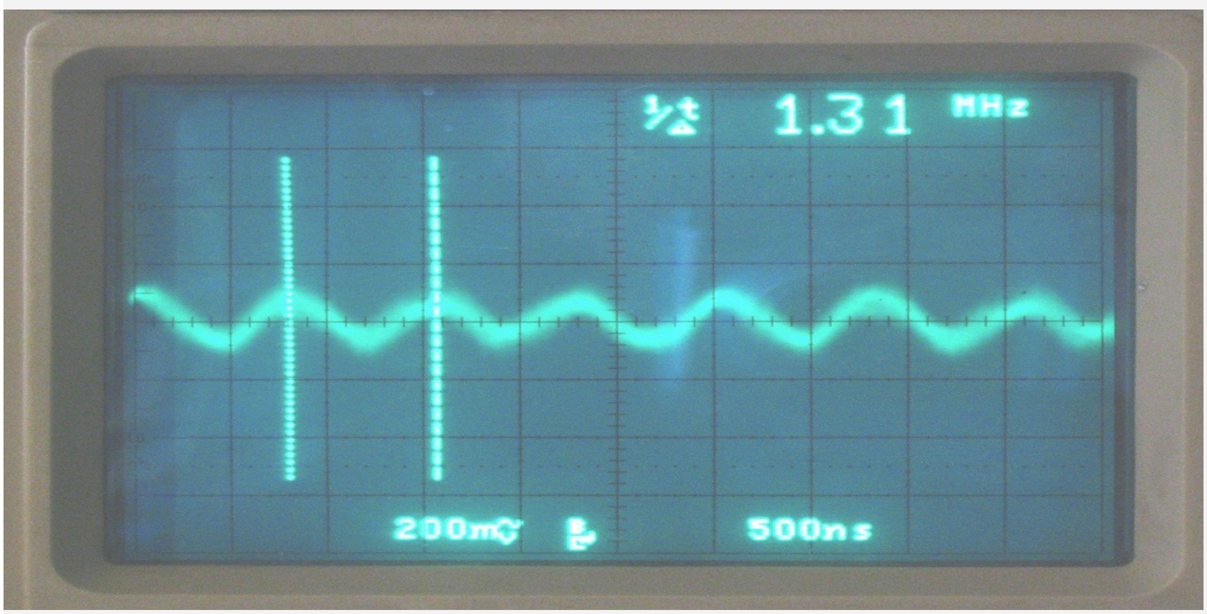


Figure 3: C1 tuned to balance with antenna.



The following measurements were taken for my 100-foot end-fed antenna.

Antenna Capacitance Versus Frequency

Frequency kHz	Fixed C pf	Var-C pf	Total C pf	Rant ohms
250	240	139	379	32
500	240	160	400	32
750	240	196	436	32
1000	240	261	501	30
1250	240	306	546	34
1320*	240	335	575	33

*local flame thrower.

It is interesting to note that the resistance of the antenna, Rant, averaged about 32 ohms. It rained heavily the night before the measurements. Normally, Rant is in the high 40s range. It will be interesting to see what happens over the winter. The above data was taken October 14, 2007.

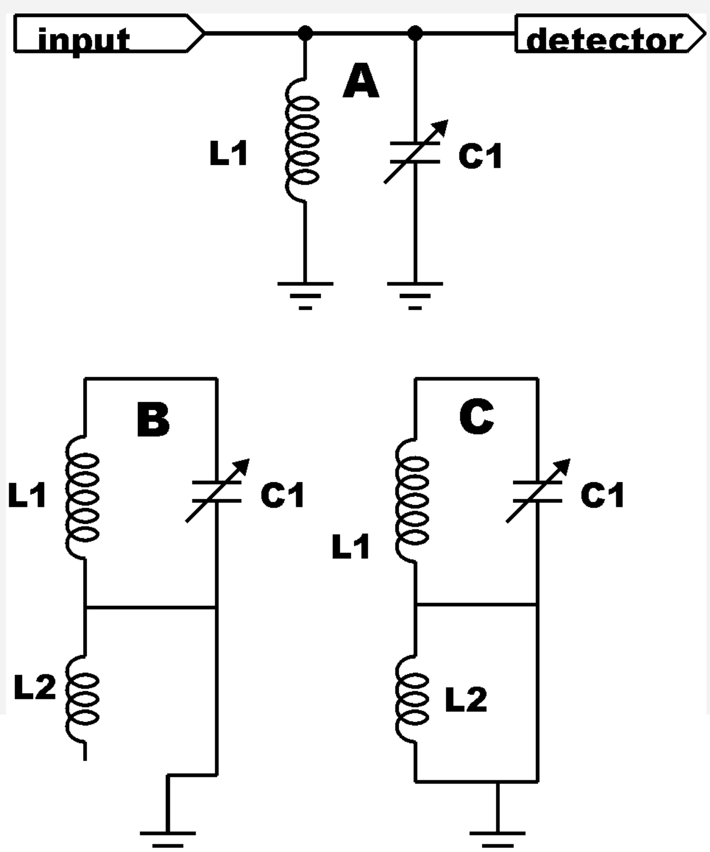
(sidebar) Trifilar Winding.

N-filar winding of a coil means to wind N pieces of wire simultaneously on a form. To reduce capacitance between the wires, they are twisted together. It's handy to use different colors for the wires, in order to ease identification after winding. My technique is to attach equal lengths of wire to the bench vice at one end and to the bit of a slow-speed drill at the other. I then run the drill at a slow speed and wind the wires together. The twisted combination is then wound on the form with the number of turns called for in the transformer.

Q of a Coil With Some Unused Turns

byXtal Staff

Figure 1



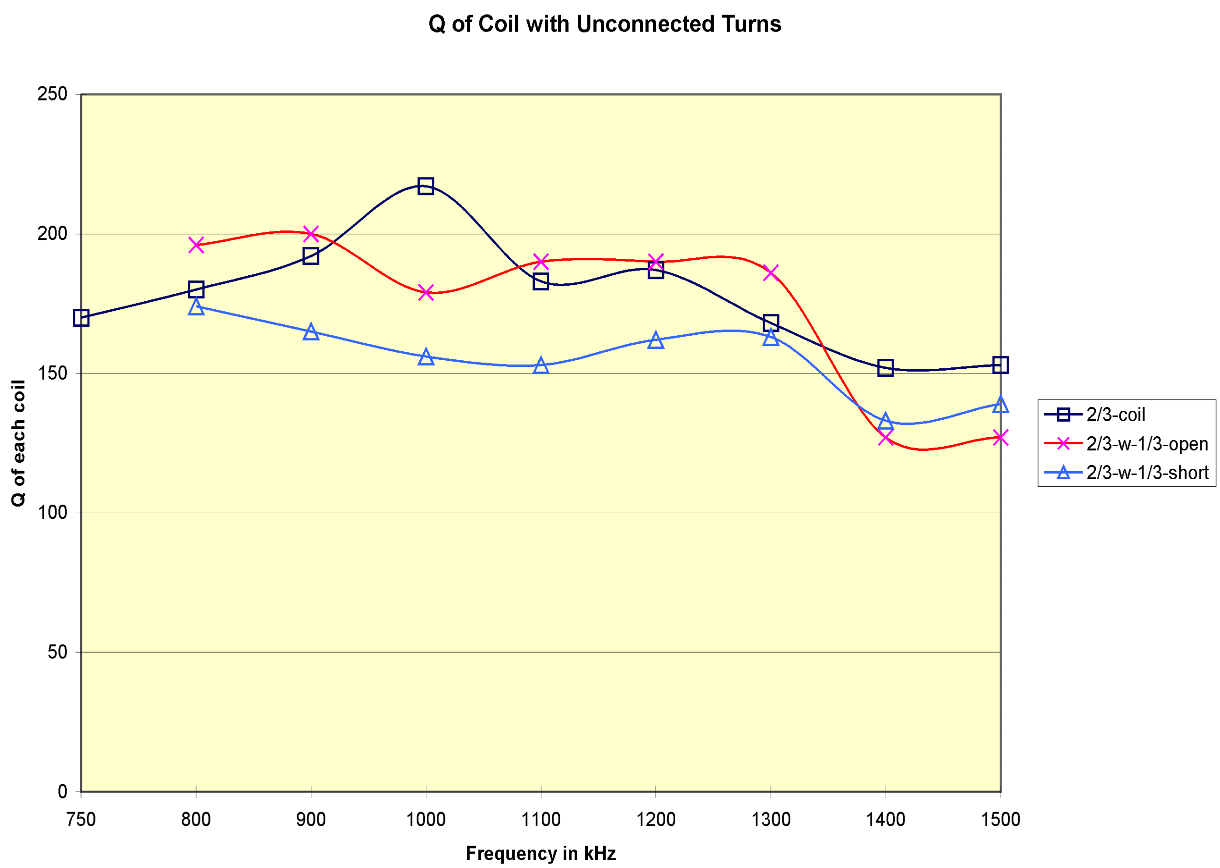
In designing a coil-based antenna tuner and/or an LC-tank for a broadcast band crystal set, coil inductance is always a concern, given the breadth of the band. Dialing the bottom of the band, ~ 500 kHz, calls for a large inductance. Tuning to the top of the band, ~ 1,600 kHz, works best – generally- with a smaller inductance. Over the years, a number of multi-coil combinations have been used to improve reception across the whole band, as compared to sticking with a single coil, traditionally 250 uH. All schemes must use some sort of coil-segment switching. One method is to simply switch in one coil for the bottom half of the band and another for the top half. A second method used is to combine two coils in series or parallel, taking into account "hot" and "ground" ends of each. A third method – outlined here and intended for intermediate grade sets – is to use just one coilbut leave a portion of it unused when tuning the top-portion of

the band. We can justify this scheme, compared with method one, if the selectivity in the top-portion of the band does not suffer much.

For example, consider a single coil made up of roughly 60 turns of #26 hookup wire, wound on a 3.5-inch ABS form, with a tap at 40 turns. Let's call the 40 turns L1 and the additional 20 turns L2, as shown in Figure 1B. There are two ways we can leave L2 our of the circuit schematic wise: leave the other end of L2 open, as in circuit B, or short both ends of L2, as in circuit C. Either way, the combination is a tank circuit made up of L1 and C1, with L2 "left out" schematically but not fully physically. This is our coil for the top portion of the band. We know, of course, that L2 is still in the "physical space." of L1, contributing capacitance to the combination.

The questions that arise are: How do the Qs of circuits B and C compare over frequency, and, how do they compare with the Q of L1 itself, without L2 present at all. We can theorize about these questions, but the quickest way to an answer is to assemble the various coil combinations and measure their Q.

Figure 2



Using a B&K 4017B RF signal generator, with digital readout, a Tekronix 2445 scope, with 10pf/10meg probe, and a 365-variable cap, the Q of each circuit arrangement was measured, using the half-power bandwidth method. Results are shown in Figure 2. The Q of circuit A, with L1 alone and circuit B, with L2 attached just to L1, are roughly the same. A local station provided some interference at 1320 kHz. The slight dip in Q at 1,000 kHz for circuit B is unexplained, "likely operator head-space." The Q of circuit C, with L1 and L2, with L2 shorted, is clearly lower all across the band. Hence, it appears that circuit B is preferred if one coil with one tap is to be used to configure bottom and top of band coils in a simple set.

THE ULTRASOUND SPECTRUM

Sound waves with frequencies above those used by humans are called ultrasound. Sounds generated or heard by humans range from above zero to near 20 kHz. The useful range of ultrasound pressure waves is from 20 kHz to roughly 10 MHz. Medical applications, such as ultrasound imaging, are probably the most familiar to the general public. Many insects, rodents, bats, and fish make use of portions of the ultrasound spectrum for feeding, communication, and navigation. Some species use both audio and ultrasound. Except for structural and medical testing, ultrasound use is nil above about 160 kHz for biological use, due to the near total absorption of the wave over short distances through the air. Table 1 notes a brief listing.

Table 1: Ultrasound Frequencies & Users		
Band	Frequency Range	Users
infrasound	0-20 Hz	elephants, whales, the earth
audio	20 Hz - 20 kHz	humans, insects, animals, fish, sonar
ultrasound	20-30 kHz	rodents
ultrasound	20-75 kHz	insects
ultrasound	20-160 kHz	bats, dolphins
ultrasound	100-2000 kHz	structures testing
ultrasound	1 - 10 MHz	medical applications
AM radio	0.5 - 1.6 MHz	AM radio

Sound pressure levels (SPL) emitted across species, recorded at about a foot, are from about 70 to 110 dB. Signals emitted vary from simple sine waves to complex waveforms with bandwidths and center frequencies as high as 120 kHz. With frequency-divider and frequency shift (direction conversion) receivers, we hear most of this activity as a pattern of clicks.

SPL is defined as follows:

$$L_p = 20\log\left(\frac{P_{RMS}}{P_{REF}}\right)\ \text{dB},$$

where P_{RMS} is the pressure and P_{REF} is the reference level at 20 μPa, the threshold of human hearing.

1 Pa is equal to (perhaps the more familiar) 10^-5 bar (10 µbar). A very strong signal at 110 SPL would represent a pressure of:

$$P_{RMS} = P_{REF}\left(10^{SPL/20}\right) = (20e-6)(10^{110/20}) = 6.3 \text{ Pa.}$$

Since the pressure of an acoustic point source is reduced by a factor of 1/r at a distance r, one can say that the signal is reduced 6 dB for each doubling in distance from the source reference point. Hence a 7 times doubling would result in a distance of 128 feet. The resulting signal would be 110 – 6*7 or -68 dB. This is still a strong enough signal to hear in a moderate gain direction conversion receive using a 40 kHz front end and 8-ohm headphones. Adding a parabolic dish to boost gain only adds range as noted below. Since pressure waves at 40 kHz loose about 0.2 dB per foot, long distance communication is uncommon.

The speed of sound in air at 0 deg C is 330 meters/second, or 1,082 ft/sec. In general it is dependent upon the combination of gases making up the media and is a function of temperature, increasing about 0.2% per degree C above 0 deg C. The velocity of sound in air can be calculated from the following:

$$v_p = \sqrt{\frac{\gamma_G P_A}{\rho_v}} = \sqrt{\frac{1.4 * 10^5}{1.29}} = 330 \text{ m/s.}$$

whereγg is the ratio of the specific heats of the gases at constant pressure and constant volume (1.4), Pa is the ambient pressure (105 n/sq-m), and ρv is the density of the gases (1.29 kg/m3), all at 0 deg C.

Many of the formulas you are likely familiar with for radio projects apply to acoustic projects. For example, the velocity of a wave in a medium is equal to the produce of its frequency and wavelength. Using this equation, we've listed the wavelength of several ultrasound signals at different frequencies in Table 2. Note that the wavelength at the popular 40 kHz experimental frequency is just 0.027 feet or about one-third of an inch. Given this fact, it is clear that a one or two foot parabolic dish can be used effectively to boost weak signals in conjunction with a piezo transducer (PZT) receiver. So, you can think of ultrasound kind of like light rather than the usual dimensions for radio projects!

Table 2: Ultrasonic Parameters

Band	Freq	Velocity	wavelength	wavelength
	kHz	Meters/sec	meters	feet
audio	1	330	0.3300	1.0827
ultrasound	20	330	0.0165	0.0541
ultrasound	40	330	0.0083	0.0271
ultrasound	120	330	0.0028	0.0090
ultrasound	1000	330	0.0003	0.0011
radio	7000	3E+8	42.8	140.6

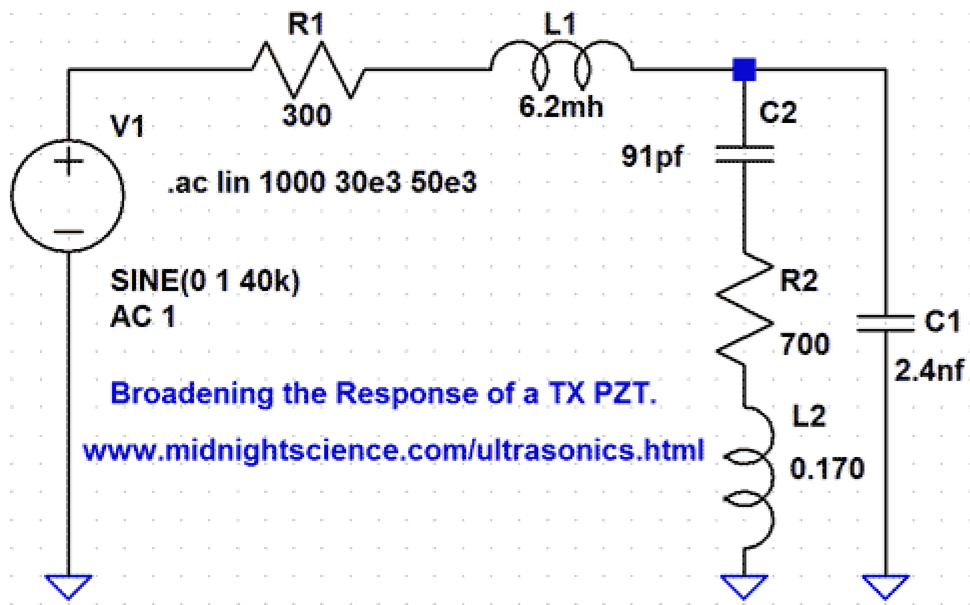
40 kHz Piezo Transducers (PZTs)

So what's a PZT? It's a passive device that produces a voltage when perturbed by a pressure wave and vice versa. Generally PZTs are optimized to work as a transmitter (TX) or receiver (RX) or sold in matched pairs. Some are designed to do both and are applied to systems such as echo-location.

For starters, the equivalent circuit of a 40 kHz PZT is like that of the quartz crystal. It consists of a series circuit composed of resistance, inductance, and capacitance – an RLC circuit – with a package capacitance added in parallel. A quartz crystal stretches/compresses when a voltage is applied across it; the PTZ produces a pressure wave when a voltage is applied and vice versa. Typical values for the parameters of TX & RX PZTs are noted in Table 1. In each case, the device exhibits series and parallel resonance. Like the quartz crystal, these frequencies are close together, for the PZT typically within 1 kHz apart. At series resonance,*f*r, the PZT's impedance is low and resistive; at parallel resonance, *f*a, – also called anti-resonance – impedance is high and resistive. Yes, you've guessed it; the rules of thumb for design with quartz crystals apply, in general, to PZTs. That means detuning, matching, and maximum power transfer techniques should be applicable to these devices as well, but of course in the 20 – 160 kHz range for most applications.

Typical Quartz and PZT Resonator Parameters						
Transducer	Frequency	R	L	C	Cp	Q
quartz	1 MHz	260	2.9 H	0.0885 pf	3.4 pf	>10k
transmit PZT	40 kHz	300	0.17 H	95 pf	2.4 nf	<10
receive PZT	40 kHz	770	.054 H	330 pf	2.4 nf	
receive PZT	1 kHz	1700	2.27 H	11 nf	77 nf	

As you may recall, quartz crystals can be "pulled" a bit, made to operate just off resonance. The same applies to PZTs. Designers typically add inductance in series with a transmit PZT or in parallel with a receiving PZT in order to force it – detune it – to operate over a broader frequency range. The schematic illustrates a simple transmit circuit, wherein the transmit PZT is detuned to operate with a nearly flat output in pressure from 35 to 45 kHz. This is reminiscent of a double-tuned circuit. Since the Q of these circuits are generally low and the PZT parameters vary even within produced lots, an op-amp synthetic inductor can be substituted to adjust tuning. Without adding a fixed inductor or the added circuitry, output pressure will be down - about -20 dB – at the band edges. Clearly, circuits without compensation are used in single-frequency applications.



In closing, viewing the voltage at the intersection of L1 and C2 with a scope – or in running a spice simulation - will display a notch at the series resonant frequency. Certainly that voltage does not display a flat response. The flat response we are looking for is the pressure transmitted by the PZT; hence, one must look at the current through the resistance, R2, in the series branch. A portion of this dissipation represents the emitted pressure wave. It does indeed provide a ~flat response when L1 and R1 are tuned.

For more detail, see our article "Measuring & Calculating Piezo Transducer Parameters" and "Broad-banding a transit PZT."

The Ultra-QP
An Ultrasound QSO Party Rig
Fun & Educational!

by Phil Anderson, WØXI

Imagine veterans and potential radio licensees gathered in a classroom, seated side-by-side facing the front, headphones on and a key at hand – both plugged into their QSO Party Rigs they each built the previous week - exchanging code as directed by designated net control! They're not just sending in a vacuum or listening to a code practice oscillator; they're communicating! Eric, 13 and a cell texting master, thinks to himself: "Gosh, this is faster than texting and I get an immediate response! When I get a direct conversion QRP RF rig I can transmit out of state! And mom isn't hassling Bob and I when we practice at home cause she can't hear ultrasound! And Bob and I can hear bats with the rig too. Way cool!"

Imagine in the previous weeks, they learned about the code and the protocol of QSO exchanges, studied block diagrams of simple receivers and transmitters, learned Ohm's Law, were told how and practiced identifying passive and basic active electronic components, learned to solder and follow kit instructions, found out how to "read" a schematic, and were introduced to a bit about radio regulation. They built the simple ultrasonic receiver-transmitter, the QSO Party Rig. They discovered the rig demonstrates a number of the concepts they discussed in radios class: selectivity, amplification, frequency conversion to the human range of hearing, automatic gain control, key control for receive/transmit, side tone to assist in sending better code, and the use of NPN and PNP transistors in a "final."

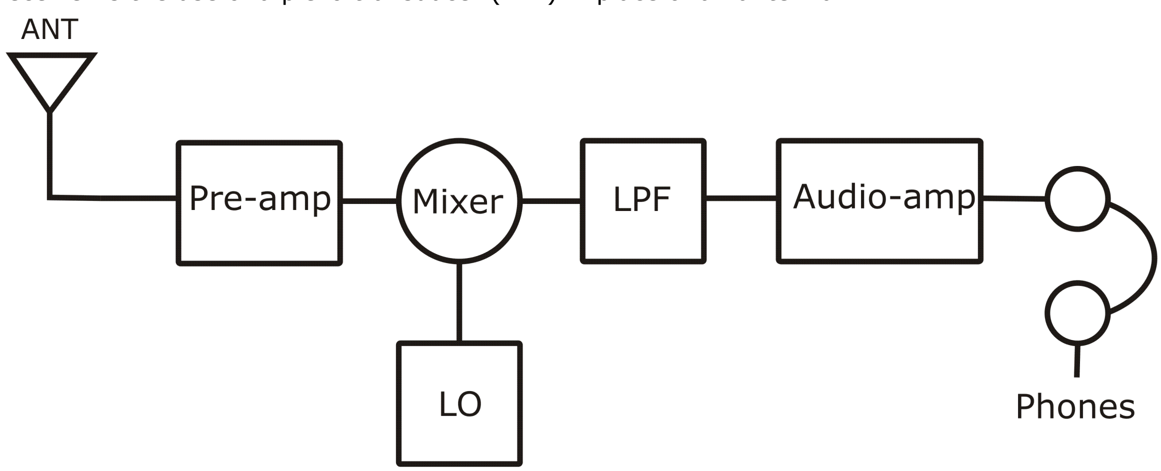
Ok! Perhaps I've gotten a little carried away, taking to heart Steve Ford's comment about my Ultra-RX1 Ultrasonic Receiver in his Short Takes column, July 2009 QST. "It's somewhat uncommon to find a product that is both educational and practical. With the RX1…you enjoy both attributes, plus the extra dimension…" of ultrasound. But wouldn't it be great, hearing Eric and his friends sending and copying Morse - at first via ultrasound and then on the air with RF? I designed the Ultra-QSO Party Rig with the above classroom "picture" in mind. The primary purpose of the Ultra-QP is to assist you and others in improving your Morse code and CW message exchange techniques. You can use the QP by itself with an earpiece or headphones as a code practice oscillator, without disturbing non-participants. They can't hear the 40 kHz ultrasound transmitted; but you'll hear the transmit side tone. Better yet, practice sending and receiving CW with a second or several Ultra-QPs in simulated on the air (pressure) exchanges. Call CQ, exchange messages, send bulletins, or send code practice in a group. No license is required.

A brief description of this rig follows: its architecture, schematic, PIC micro-controller and firmware. While the RX1 is a direction conversion, wide-audio receiver, this rig utilizes frequency division for reception and a push-pull transmit final.

Direct Conversion and Frequency Division Receivers

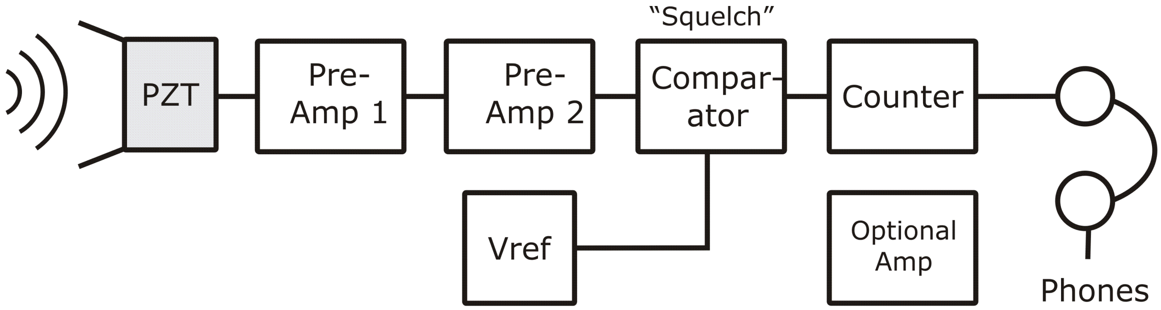
The traditional receiver architecture for QRP rigs is direction conversion, as shown below. Usually an RF pre-amplifier is added, as noted. The carrier signal is "beat" by a local oscillator (LO), offset in frequency by the audio frequency desired, using a mixer circuit. Since mixers create an abundance of signals – both desired and undesired – a filter is added to remove the RF tidbits. Given that the level of the desired input signal is low – on the order of tens of micro-volts at best – an audio amplifier is added, often the ubiquitous LM386 IC.

This signal processing scheme works well for ultrasound and sonar systems too. The Ultra-RX1 receiver converts 35 – 45 kHz pressure waves to the range of human hearing. As such the LO tunes the same range as the pressure waves but is offset by 700 Hz. The only difference between it and the RF receiver is the use of a piezo transducer (PZT) in place of an antenna.



An alternative and inexpensive architecture for ultrasound receivers is frequency division reception (FDR), as noted in Figure 2. Since the sound pressure levels (SPL) of desired ultrasound signals tend to be very low, a two stage pre-amplifier following the transducer is the norm. The signal is then converted to digital and divided by a counter, rather than mixing. The audio is recovered by attaching

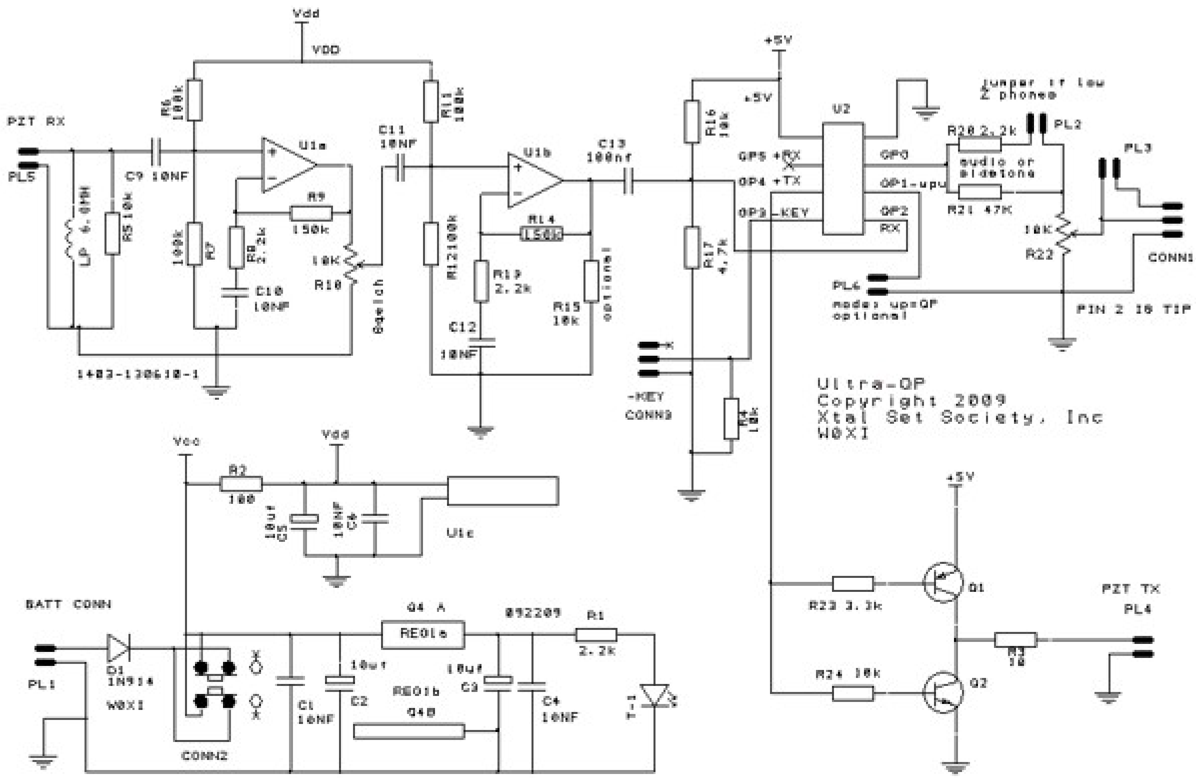
the phones – via a potentiometer – to one of the taps of the counter. For example, a 40 kHz signal divided by 64 emerges as a 625 Hz tone. While not desirable as an RF receiver architecture, the FDR will work. You could build a 40-meter version to monitor the transmissions of the OM next door. Great DX!



QRP and Ultrasound Transceivers

When the LO of an RF QRP direction conversion receiver is buffered and used as the source for transmission, the plain vanilla QRP transceiver architecture emerges. To hear another station calling that zero-beats this rig, the LO must be pulled for either reception or transmission. In addition, to assist the operator in sending good code, muting the receiver and including a side tone for the phones increases code proficiency.

For an ultrasound transceiver, the same architecture can be used, as noted in the schematic for the Ultra-QSO Party Rig, displayed below. Let's relate the receiver stages with the block diagram. Starting at top-left, the leads of an ultrasound transducer (PZT) feed U1, a dual-operational amplifier. Total gain at 40 kHz is set at or above 20,000! A pot is introduced between the stages to provide for "squelch." To save chip count and increase circuit flexibility, the usual comparator and counter functions are implemented with a 12F629 PIC micro-controller and its stored program (firmware). The resulting audio output is a constant TTL square wave when a carrier of sufficient strength enters the PIC's Timer0 Schmitt input. Audio listening level is set by POT R22 and hi-Z phones/crystal earpiece is accommodated with/without a shunt at header PL2. To enable the use of a pair of low-Z stereo phones, such as Sony's 24-ohm MDR-V150, a jumper is placed on the two-position header PL3.



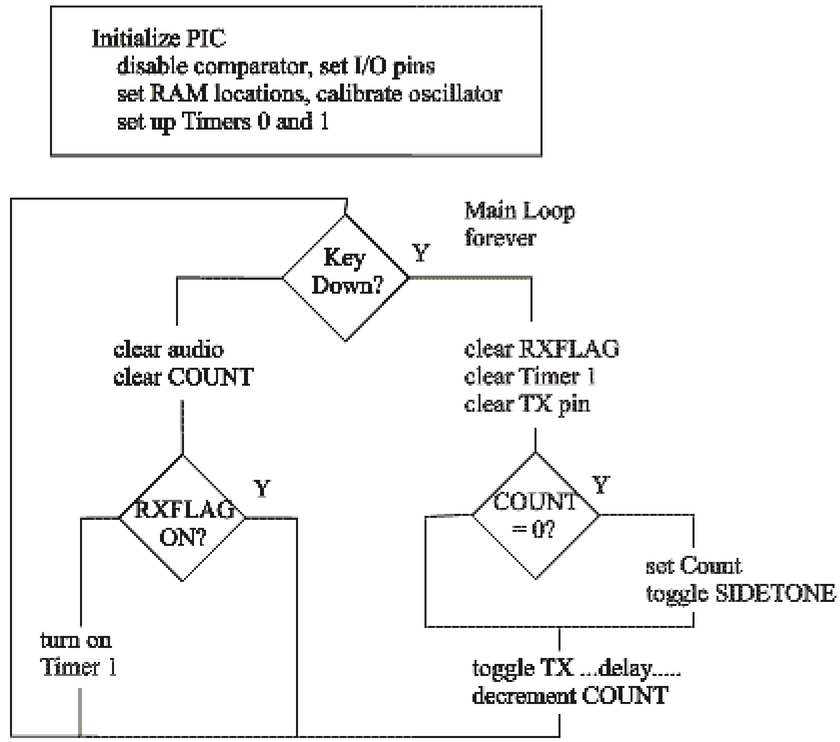
The transmitter side of the rig is super simple with the assistance of a PIC microcontroller. When the code key is grounded, pin 5 of the PIC is grounded, initiating transmission. The PIC developed transmit oscillator then drives the PNP-NPN final via pin 3 and the side tone is sent to audio out, pin 7.

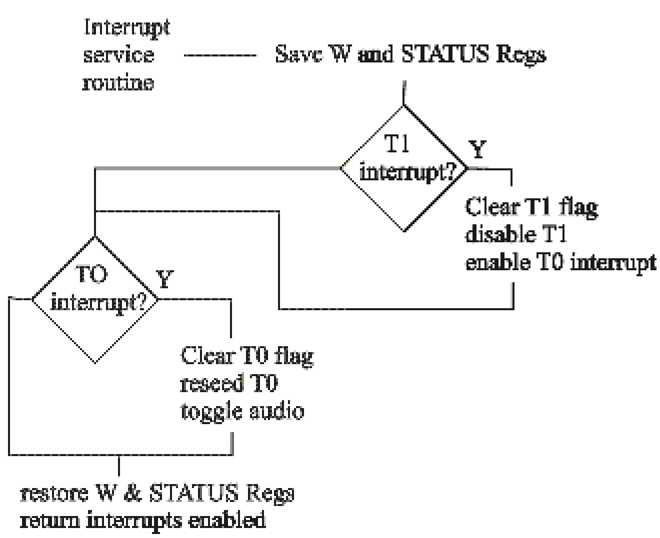
The circuitry at bottom-left includes an input protection diode, power switch, 2950 low dropout +5 V regulator, power-on LED, and RC decoupling. The op-amps run on the battery power while the PIC and transmit final run at + 5 volts. PIC timing is derived from the calibrated internal RC oscillator.

PIC firmware supplies the divide-by function, AGC, TX oscillator, audio, and QSK delay

Without a micro-controller, the receive counter, squelch, muting, side-tone, and the audio and transmit oscillators can be supplied with discrete chips. In fact, I built an ultrasound transceiver that way – the Ultra-TR40 - and it works fine. Using the PIC and firmware, however, increases design and product flexibility at reduced cost. For this project the 8-pin 12F629 has enough power, a small footprint, can be reprogrammed in assembly or C and its flash memory can be burned in with the inexpensive PICSTART PLUS prom programmer.

I prefer assembly language programming over C when a program is short and time dependent. A flow chart for the program code is shown below. As usual, an initialization subroutine is called that configures the hardware and various software parameters. The comparator of the 12F629 is turned off; I/O pins are set as inputs or outputs; RAM is set aside for variables; the internal 4 MHz oscillator is selected and calibrated; and Timers 0 and 1 are configured.





The main program loop runs “forever;” running through the receiver (RX) or transmit (TX) sub-loop based on the status of the sampled Key input. Timer 1 is used to develop a QSK delay and Timer 0 is used as the frequency divider. Since the internal calibrated oscillator runs at 4 MHz, machine instructions run at a 1 MHz clip.

Main first tests the status of the key. If down it takes the TX branch and clears the RXFLAG. Each time through the branch it toggles the TX output line and every COUNT times through it toggles the transmit side-tone output. The side-tone uses the same audio output pin as that used for receive. To keep the TX timing constant, each possible branch through the TX loop must take exactly 25 microseconds. It’s the old “N NOP instructions to success” strategy.

When the key is first lifted (or at power up), Main goes through the RX loop with the RXFLAG off and turns Timer 1 on. After that it continues to go through the right side of the RX loop, doing nothing.

Once Timer 1 interrupts, after 512 ms (see the interrupt service routine at the bottom of the flowchart), it's turned off, the interrupt flag is cancelled, and Timer 0 is enabled. After that, the audio output is toggled with each Timer 0 interrupt, denoting the input signal has been divided down to audio.

So there you have it. The Ultra-QP provides a platform for sending and receiving code in a classroom setting yet similar to that on the air. Code can be sent and received; near break-in operation is simulated, audio level is maintained constant, and a side-tone helps the sender to key better code. Join the ultrasonic QSO party!

Acknowledgments & Notes

Special thanks go to these Ultra-RX1, Ultra-TR40, and Ultra-QP beta testers: Philip Tate, M1GWZ (UK); Joe Eisenberg, NØNEB; Bob Grove, W8JHD; Randy Rathburn, NVØU; Jeff McCright, KDØGCL, Bob Blank (landlord of two occupied bat houses), and Stan Roth, biologist.

The Ultra-QSO Party, while using a frequency-conversion receiver, can be used to monitor bats and insects that produce coherent ultrasound transmissions. Short tone bursts at 35 to 45 kHz are converted to short audio bursts of 600 to 700 Hz. The transmitted signal levels are not preserved; all detected signals produce the same audio volume. The Ultra-RX1 on the other hand converts the whole spectrum of 35 to 45 kHz to a sampling of audio from 0 to 10 kHz and transmit source volume is maintained, thus assisting one in judging changes in distance of a moving object, bat or insect. Summer and fall evenings are good times to monitor bats; they hibernate during the winter. Man-made ultrasonicsabound in your home and at the office. Enter the following web address (URL) to listen to a windows media file of bugs and beetles chatting in my lawn in October in Kansas, recorded with the Ultra-RX1, windows media file. Listen to this CW file to hear CW sent from one Ultra-QP to another over 20 feet.

A complete kit of parts, including RX and TX transducers, a 4580DD op-amp IC, programmed 12F629 PIC, PCB, case, and passive components is available from the Xtal Set Society for $49.95 plus shipping/handling at www.midnightscience.com/ultrasonics.html. Assembly time for the active kit builder is about an hour.

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